ANALYSIS OF FLOOD RISK AND VULNERABILITY IN KANO METROPOLIS, KANO STATE, NIGERIA

BY

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A THESIS SUBMITTED TO THE SCHOOL OF POSTGRADUATE STUDIES, AHMADU BELLO UNIVERSITY, ZARIA IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF DOCTOR OF PHILOSOPHY DEGREE IN GEOGRAPHY

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DECLARATION

I declare that this thesis entitled "**Analysis of Flood Risk and Vulnerability in Kano Metropolis, Kano State, Nigeria**" has been carried out by me in the Department of Geography and Environmental Management under the supervision of Professor E. O. Iguisi, Professor A. Ismail and Professor A. A. Ibrahim. The information derived from the literatures has been duly acknowledged in the text and a list of references provided. No part of this thesis was previously presented for another degree or diploma at any other institution.

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Signature **Date**

CERTIFICATION

This thesis entitled "**Analysis of Flood Risk and Vulnerability in Kano Metropolis, Kano State, Nigeria**", meets the regulations governing the award of the degree of Doctor of Philosophy (Ph.D) in Geography of Ahmadu Bello University and is approved for its contribution to knowledge and literary presentation.

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DEDICATION

This work is dedicated to my late Father, AlhajiMalamijo Ibrahim and my mum HajiyaHauwa Suleiman.

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ABSTRACT

Flooding has been a major threat to human life and properties in Kano metropolis in recent years, but information on the drainage pattern, response of the changing drainage basin to rainfall events, level of vulnerability and risk on a sub-drainage basin level which are fundamental to tackling flooding incidences are scanty. This study analyses flood risk and vulnerability within sub-basin in Kano metropolis. This was achieved through assessing the responses of different land uses and land cover to rainfall events and the changing social, economical, environmental and physical indicators.The study looked at the change in land use land cover (LULC) from 2001 to 2035 and thereby assessed the response of this different land covers to rainfall event using the Hydrologic Engeneering Corps- Hydrologic Modelling System(HEC-HMS) model. The study further used some set of indicators to determine Flood Vulnerability level using the flood vulnerability index (FVI) within the basins. The outcome of the LULC revealed that the built-up areas increased from 19.7% to 34.4% and then to 54.4% in 2001, 2012 and 2035 respectively. The discharge of Jakara basin indicated a rise from 2001, 2012 to 2035 in the order of 443, 585.2 to 609.7 cm^3/sec respectively. However, that of Chalawa shows increase between 2001 and 2012 and a decrease in 2035 as a result of canalization within the basin. The average FVI for the Jakara Basin was 0.6, 0.5 and 0.4 in 2001, 2012 and 2035 respectively. This indicates an increase in adaptive/resilience to flood within the basin eventhough highly vulnerable to flood in 2001. The average risk is 17.5, 19.0 and 16.9 in 2001, 2012 and 2035 respectively. The rise in the average risk values in 2012 is as a result of an increase in economic and physical vulnerability and an increase in discharge giving a moderate flood risk. The Chalawa basin was 0.4, 0.5 and 0.4 for flood vulnerability and a flood risk score of 13.0, 21.6 and 17.2 respectively.This also reveals a high vulnerability especially in 2012 and also high risk.

This generally indicates high vulnerability and moderate risk for Kano metropolis within the study period. The study recommends establishment of flood early warning systems, gauging staions at junctions of the sub-drainage basins, flood insurance, an increase in the number of emergency service workers, and creation of canals to convey run-off out of the basins.

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CHAPTER ONE

INTRODUCTION

1.1 Background to the Study

Flooding is reported to be the most common natural hazard, and has affected a greater number of people than any other natural disaster (Green, Parker, and Tunstall, 2000; Brivio, Colombo, Maggi, and Tomasoni, 2002; Vlachos, 2010; Centre for Research on the Epidemiology of Disasters (CRED), 2011). In 2013 the number, extent, and global impacts of flood events have been extraordinary, and have accounted for almost 47% of global economic losses from natural disasters (Wake, 2013). Over the last thirty years, a total of 3,119 floods have been reported worldwide; these floods have resulted in the deaths of more than 200,000 people and have affected more than 2.8 billion others (Jakibicka, Phalkey, Marx, Vos and Guha-sapir, 2010).

Floods are bodies of water from runoff, river, or tidal origin, which rise to overflow onto normally dry land. Natural flood plains have been heavily transformed by human activities, especially in recent years (Turner,Clark,Kates.,Richards,Mathewsand Meyer,1990) to the level that natural environment cannot absorb flood water easily any more. The transformation in the natural system on the one hand and reliance on the productive and regulatory role of flood plains on the other hand make human settlements more susceptible to the impacts of flooding, and it is therefore more likely that a natural hazard will turn into a social disaster.

In response to the great damage from flooding and societies' demand for improved flood disaster management throughout the world, a rethinking of functions and management practices is taking place. Comprehensive Emergency Management (CEM) is the

profession and skill of applying science and technology to manage and deal with disasters that can inflict enormous amounts of damage on nations (Drabek and Hoetmer,1991; Committee on Planning for Catastrophe: National Research Council, 2007).

In the field of disaster management, the term 'Risk and Vulnerability Assessment' is well known for its contributions towards reducing the impacts which disasters bring to communities. Scientific discussion on the coupled functions of human and biophysical systems of Risk and Vulnerability (Adger, 1999; Berkes, 2007) has inspired the development of a variety of conceptual and analytical frameworks.

Risk can be defined as the probability of a loss or the actual exposure of something of human value to hazard and often regarded as the combination of probability and loss.Vulnerability may be defined as the conditions determined by physical, social, economic, and environmental factors or processes, which increase the susceptibility of a community to the impact of hazards (UNISDR, 2005).Hazard is a threatening event, or the probability of occurrence of a potentially damaging phenomenon within a given time period and area. According to Alexander (1993)hazard could also be referred to as the probability of a potentially dangerous phenomenon occurring in a given location within a specified period of time (Smith, 1996; Sinnakaudan, AbGhani, Ahmad and Zakaria, 2003).

Urbanization aggravates flooding by restricting where flood waters can go. In an urban area, large parts of the ground are covered with roofs, tarred roads and pavements. These obstruct sections of natural channels, infiltration and built drains that ensure water movement to rivers faster than it could under the natural conditions. Another factor in an

urban setting is the population density. As more people crowd into cities like Kano Metropolis, so does the floods effectintensify because of the tendency to create more impervious surfaces. Consequently even quite moderate storms could produce high flows within a drainage basin because there are more hard surfaces than drains (ActionAid International, 2006). In extreme cases urban floods can result in disasters that setback urban development by years or even decades. Given the high spatial concentration of people and values in cities, even small scale floods may lead to considerable damages. Recent statistics clearly indicate that economic damages caused by urban floods are rising (MunichRe, 2005).

It is displeasing to note that, urban areas in Nigeria are particularly vulnerable to flooding due to inadequate drainage system; changes in ecosystem through the replacement of natural and absorptive soil cover with concrete; and deforestation of hillsides, which has the effect of increasing the quantity and rate of runoff.In the developed countries, flood forecasting and prediction, flood control and mitigation, early warning systems, disaster response and management have been in the forefront, however in most developing countries (including Nigeria), these responses are mostly inadequate. Flood early warning, prediction, and mitigation would have rather been better programmes than search and rescue, relief and rehabilitation programmes found in developing countries (Jeb, 2013).

Assessing flood hazard and related vulnerabilities often require knowledge of land use and land cover, run-off rate as well as human and environmental attributes of the communities. Land use and land cover (LULC) models such as the Markov model is a class of probability model used to study the evolution of a system over time. Transition

probabilities are used to identify how a system evolves from one time period to the next. A Markov chain is the behavior of the system over time, as described by the transition probabilities and the probability of the system being in various states.

Hydrological models are regarded as powerful tools for predicting drainage basin response to rainfall events and assessment of impacts of parameters such as land-use andcover change on drainage basin hydrology (Whitehead and Robinson, 1993).The complexities of global flood disasters need a much technical approach than the conventional methods used, this will lead to a more effective management, reduction and forecasting of flood events. Alghmand, Abdullah, Abustan and Vosoogh (2010) reiterated that information on drainage basin characteristics and response torainfall help reduce risk and vulnerability levels within the basins and mitigate futureoccurrenceof flood events.

1.2 Statement of the Research Problem

According to a recent study on rainfall dynamics and climate change in Kano, it was revealed that in the last two decades rainfall has increased considerably in both amount and duration (Mohammed, Abdulhamid, Badamasi, and Ahmed, 2015). As a result of this,annual floods occur within Kano Metropolis causing severe damages to properties and lives. Because of this, huge funds are lost to compensation and rehabilitation, yet the problems are unabated. Within the Metropolis, residents live in fear of being drowned or buried under the rubbles of their homes as a result of annual flooding during the rainy seasons.

Kano State has suffered severe flood especially the flood of the 1980s and the 2000s that ravaged northern Nigeria. Conversely, flood disasters as a result of heavy rainfall have been recorded. In August, 1988 for example, severe flooding in Kano State resulted in the loss of 146 lives, destruction of 180,000 houses, washing away of 14,000 farms, displacement of 200,000 people, and damage to residences and infrastructure worth 560 million naira (NEST, 1991). Similarly, in June 2011, 24 people lost their lives and many others injured, about 100 houses were destroyed, and more than 300 people were displaced after torrential rains flooded the highly populated Kano city (Ibrahim, 2011). On August 28, 2012, some Local Government Areas including Nassarawa, Fagge and Gwale were affected by floods as a result of heavy rainfall in which 15 lives were lost. The August 11, 2013 flood also claimed lives and destroyed 434 houses in Kano metropolis (Vanguard Newspaper, 2003). Studies have been carried out to ascertain the level of flood vulnerability and risk in Kano as a result of the past frequent flood events.

Yahaya, Ahmad and Abdallah (2010) used pairwise comparison method (PCM) and ranking method to calculate the contribution of annual rainfall, basin slope, drainage network, land cover and soil type to flood vulnerability in Kano. Likewise Nabegu (2014) assessed vulnerability of households to flooding in Kano using questionnaire survey, infrastructure analysis and flood impact information of 2012 flood disaster. These studies fall short of addressing the effect of land use and land cover change on run-off and how it affects the level of the components of flood vulnerability and their subsequent effect on flood risk.

Kano metropolis consists of two drainage basins (Jakara and Chalawa) and several sub-basins which control runoff events. A study of flood risk and vulnerability levels based

on individual sub- drainage basins would be a better approach than considering political boundaries that have little or no control on runoff pattern, volume and probable flood occurrences. This study used a different approach by looking at the effect of increased imperviousness as a result of land use and land cover change and the subsequent response of the drainage basins to rainfall events using the HEC HMS model.The flood vulnerability level was assessed using the Balica (2012) flood vulnerability index (FVI) method by looking at all components (social, economic, physical and environmental) through indicators that either increase or decrease the level of flood vulnerability. The hazard (run-off) and vulnerability level were combined using the Sengtianthr (2013) approach for the risk level at sub-basin level. These methodologies have proven to be far more effective and holistic than the conventional methods of the preceding studies especially in the works of (Alghamand, etal.2010, Balica, 2012 and Sengtiathr 2013). Based on this, the study adopted the aforementioned approaches.The study addressed the following research questions:

1. What is the nature ofland- use land-cover change in Kano Metropolis?
2. What is the run-off volume within Kano Metropolis?
3. What is the level of flood vulnerability in the metropolis?
4. What is the magnitude of flood risk in Kano Metropolis?

1.3 Aim and Objectives

The aim of the study is to analyse flood risk and vulnerability in Kano Metropolis.

This aim will be achieved through the following set of objectives, which are to:

i. conduct a land-use and land-cover change analyses of the metropolis

ii. determine the volume of run-off within the metropolis

iii. conduct a flood vulnerability analysis of the metropolis

iv. determine the flood risk of the metropolis

1.4 Scope of The Study

This study covered the entire Kano metropolis comprising of eight Local Government areas (Municipal, Gwale, Dala, Fagge, Tarauni, Nassarawa, Kumbotso, and Ungoggo). The study looked at land use and land cover change, amount of run-off, level of flood vulnerability and risk.The temporal span of the study covered 2001, 2012 and a projection to 2035.These are periods that widespread flooding was experienced within the study area and the year predicted by the UN/ISDR (2005) for maximum reduction of flood disasters.

1.5 Limitation of the Research

Although the objectives of the study have been achieved there are limitations which are outlined below:

1. The study is constrained by inadequate runoff discharge data from gauging stations
2. Inadequate availability of funds/grants for wide coverage ground truthing.
3. Lack of availability of data on some important indicators at drainage basin level or local government level such as Human Development Index, Flood Insurance, Disaster, Shelters and Cultural Heritage.

1.6 Justification of the Study

Floods are among the most devastating natural disasters in the world, claiming more lives and causing more property damage than any other natural phenomena. In Nigeria though not leading in terms of claiming lives, flood affects and displaces more people than any other disaster (Askew, 1999). Flooding in various part of Nigeria have forced millions of people from their homes, destroyed businesses, polluted water resources and increased the risk of diseases outbreak (Baiye, 1988; Akiyemi, 1990; Nwaubani, 1991; Edward and Adebiyi,1997).

People living in developing countries like Nigeria are particularly vulnerable to flood disasters as they often live in high risk areas, have lower coping capacities, and limited early warning or mitigation strategies (Shi and Wang, 2010). For instance in August 1988, 142 people died, 300000 people were displaced, 18000 houses were destroyed and 1400 farms were swept away in Kano following a flash flood (Durotoye, 1999).

When floods occur in less developed nations, they can effectively wipe out decades of investments of infrastructure and result in loss of lives. The greatest tragedy is that most of these deaths, social and economic hardship can either be avoided or drastically mitigated through flood forecasting and warning systems such as vulnerability and risk studies, prediction of possible flood scenarios using computer models and simulations, hence the need for this research.

CHAPTER TWO

CONCEPTUAL FRAMEWORK AND LITERATURE REVIEW

2.1 Definition of terms

The climate of an area is its average weather over a period of time, which might be a few months or a few years (Houghton 2009). Climate and global environmental change are familiar topics which we all hear about on the news. One of the main outcomes of global climate and environmental change is a rise in the quantity and severity of extreme events. Flood is one of the weather-related natural hazards, and has been highlighted in this research owing to its high impact on human settlements.

2.2 Flooding

Floods are the most frequent and devastating type of natural disaster (International Federation of Red Cross and Red Crescent Societies (IFRCRCS), 1998; Bogardi, Damm and Fekete, 2010;CRED, 2011).The underlying reason is the extent and excess of river valleys in the geographic areas where humans have been most interested in residing. Flood impacts on the settlements are increasing, owing to both increased severity of flooding and humandriven factors. In fact, there are many causal agents of flooding, which vary over time and space: urbanization, deforestation, land use change, flood

plain development, increase in population migration, the increasing value of flood-affected properties, coastal erosion, changes in social environments, poor drainage, lack of knowledge and experience related to flooding, changing and straightening of the river beds, soil sealing, and climate change (Penning-Rowsell, etal., 1992; SchmidtThomé, 2006; The Department for Communities and Local Government, 2006;Bogardi, et al 2010;Jakibicka,et al., 2010;Vlachos, 2010).

Floods are a component of the dynamic process of the hydrological cycle, although they havea variety of causes. Jakibicka *et.al* (2010) defined rainfall, melting snow, glacial outbursts, and dam breaks as the leading causes. Floods have been largely understood to be related to rainfall pattern, climatological factors, terrain and topography, antecedent conditions, and stream networks; however, climatic shift, mega-ruptures, metabolism, socio-political context, trans-boundary dependencies, and the fast pace of technological development have portrayed a process of complexification for flooding (Green, et al., 2000; Jakibickaet al., 2010;Vlachos, 2010). Various definitions of flooding have been proposed:

i. A significant rise of water level in a stream, lake, reservoir or coastal region (CRED, 2011).
ii. Water accumulation that is not submerged (Jakibicka*et al.*, 2010)
iii. The result of runoff where runoff depends on the intensity and areal extent of the precipitation (Green*et al.*, 2000).
iv. Floods are high-water stages where water overflows its natural or artificial banks onto normally dry land (Schmidt-Thomé, 2006).

v. A flood is a body of water which rises to overflow land which is not normally submerged (Ward, 1978).

In this research, however, ‘flood’ is defined as a body of water from runoff, or river origin which rises to overflow onto normally dry land.

Floods have some measurable characteristics, comprising depth, discharge (magnitude, volume), frequency (return period), duration, velocity, extent, and seasonality (Green,*et.al*., 2000). Despite all these facts, floods are only hazardsand not disasters; they are threats to human life, infrastructure and other valuable resources. For some regions they are part of life and may even be seen as beneficial. However, there are complex and varied negative impacts of flooding on human settlements, such as death, injuries to physical and psychological health, damage to infrastructure and buildings, and losses to farmlands and crops (Werritty *et al.*, 2007; Eulisse, 2010).

“Floodplains are areas where either they are ecologically important wetlands, or they were such areas in the past, and are also areas that have competitive advantages for human settlement” (Green*et al*., 2000). On the other hand, flood plains are generally low-lying land, close to rivers and therefore in flood risk zones. And here comes the problem: human settlements on flood-prone land where flood hazard might turn into disaster. Runoff and drainage control systems are among the flood mitigation strategies that can be applied in these areas, but sufficient knowledge on the amount of Runoff is of importance. Integrated flood risk management is a preliminary solution where understanding hazard, risk and vulnerability are the key factors.

2.2.1 Flood types

Floods can happen anywhere and anytime. They have been a great problem for societies since settlements have been located in low-lying flood plains. Other factors such as soil sealing through paving and the changing, straightening and relocating of stream beds also contribute to the severity of the issue. The type of flood is linked to the source of flooding.

The main sources of flooding or flood types are:

1. **River flooding**: when the amount of water directed into the river bed exceeds its capacity and therefore water overflows to the adjacent land. In large and flat areas the flood level rises slowly, giving appropriate time for action and warning. But in steep and small catchments it is more likely that flash floodswill happen, when there is a rapid rise in the water level with little time given for warning and emergency action.
2. **Coastal flooding:** This type of flooding is the result of storm surge or high tides and can be more serious than river flooding. A number of factors can participate in tidal flooding, such as weather, wind, waves, topography, height of tides and flood defences.
3. **Surface (or land) flooding:** Surface water runoff is caused by intense rainfall, often in short duration, which cannot soak into the ground or flow into the drainage system, or sometimes as a result of overwhelmed rivers and watercourses. This kind of flooding is usually difficult to predict and its severity is highly relevant to topography and the permeability of the ground.

4. **Groundwater flooding**: Groundwater is water below the surface of the ground, and this type of flooding happens when the water level rises above the surface elevation. Low-lying, permeable areas such as chalk or sandstone are more susceptible to this type of flooding. Groundwater flooding takes weeks or months to subside as the groundwater flow is much slower than that of surface water.
5. **Sewer flooding**: In urban areas, surface water and sewage are directed into the sewer system. When sewers become blocked or overwhelmed by heavy rainfall, land and property are highly at risk of flooding. This type of flood is usually polluted and is likely to contaminate river flows as well.
6. **Reservoir flooding**: Reservoirs contain high volumes of water above the surface elevation. Although the safety of dams is high and standard there is still a possibility of failure resulting in flooding.

2.2.2 World flood trends

Flooding is reported to be the most common natural hazard and has affected a greaternumber of people than all other natural disasters (Green,et al. 2000;Brivio, etal. 2002; Vlachos, 2010; CRED, 2011). Even in 2013, the number, extent, and global impacts of floodevents have been extraordinary and have formed almost 47% of global economic losses from natural disasters (Wake, 2013). Over the last thirty years, a total of 3,119floods worldwide have been reported in Emergency Events Database(EM-DAT); these floods have resulted in thedeaths of more than 200,000 people and affected more than 2.8 billion others (Jakibicka, et al. 2010).

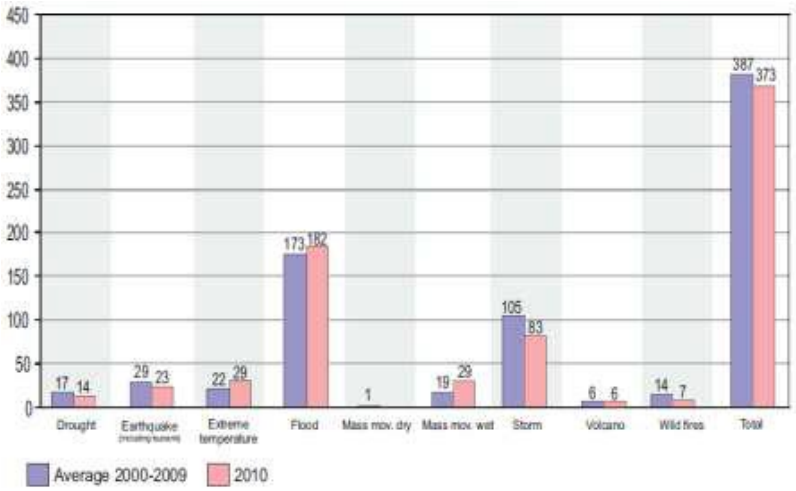


Figure 2.1: Natural disaster occurrence by disaster type (2000-2010)
Source: Adapted from EM-DAT: The OFDA/CRED International Disaster Database

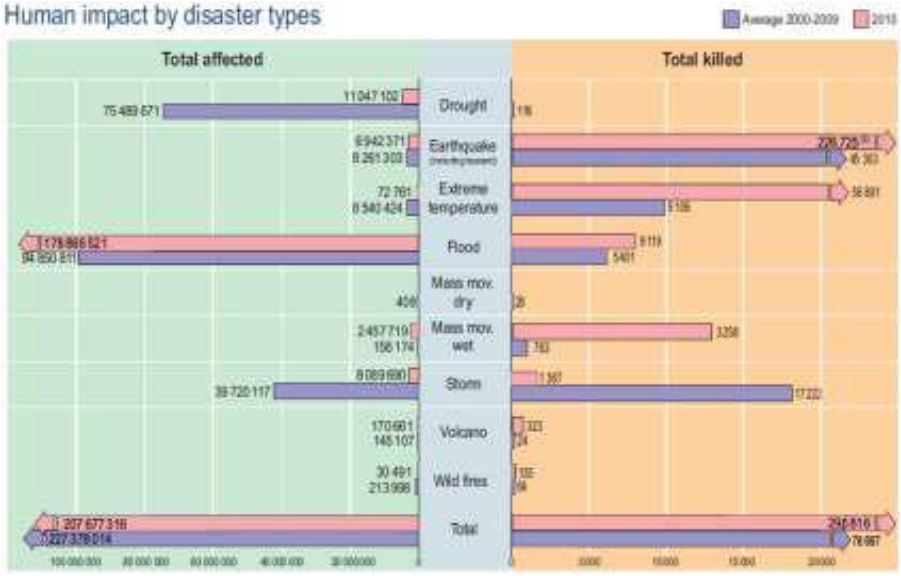


Figure 2.2: Human impact by disaster type (2000-2010)
Source:Adapted from EM-DAT: The OFDA/CRED International Disaster Database

Nearly half of the natural disasters reported in 2010 were floods (Figure 2.1). Inaddition, flooding has the most impact on human life (people killed or affected) of allnatural disasters, as shown in Figure 2.2. Furthermore, the occurrence (Figure 2.1) andhuman impact (Figure 2.2) of floods have been increasing.

2.2.3 Flooding in Nigeria

The impacts of flooding have increasingly assumed from significant to threatening proportions, resulting in loss of lives and properties. Though detailed statistics are not available regarding the losses sustained by the urban dwellers and other flood victims, it is obvious from the available records that irreparable havocs have been sustained by the citizen of Nigeria due to what has become perennial natural disaster in our cities. Apart from houses that collapse by flooding, schools buildings and bridges sometimes collapse as well. Markets places and farmlands are submerged for weeks and sometimes are washed away (Etuonovbe, 2011).

Devastating floods had hit more than twenty one states of the Federation with Borno, Jigawa, Kano, Lagos, Niger, Oyo, Taraba and Yobe States recording the highest tolls of casualties. It is obvious that more than four thousand houses in over ninety four (94) communities were washed away by floods and rainstorms when more than one million (1 million) people were rendered homeless, an estimate of over one thousand five hundred and forty nine (1,549) people lost their lives. The report of Sunday Times, August 21, 1988 however, revealed that among those that were mostly affected or killed by floods were children and women.

Previous studies also reported that communications and traffic are interrupted while most of the areas are inundated, social and economic activities are paralyzed during floods. Besides, untold hardship is experienced, especially by the most vulnerable groups (women and school children) whenever there is flood disaster (Oluduro, 1998; Durotoye, 1999; Folorunsho and Awosika, 2001).

2.2.4 Flood management

Flooding is part of the natural process and it is not financially or logically beneficial to protect all properties against it; we need to prepare for it. In a research by Keogh *etal*.(2011) for Queensland, Australia, it was revealed that connections between and within social and institutional bodies play a vital role in the community's coping. Preparing staff adequately for extreme events, keeping people and staff informed regularly, providing appropriate temporary accommodation for elderly people and children, and testing the warning systems are other factors that can boost adaptation (Keogh,et al. 2011).

The logical approach to flood management starts by understanding the problem. Identifying available options is the next step which involves the process of decisionmaking. Decision making is complex and our knowledge is limited; therefore, costbenefit and multi-criteria analyses are tools that can help us. Finally, the best available option needs to be selected; this option will be appropriate to local conditions with regards to public outlook, maintainability, and adaptive capacities (Green, *et.al.* 2000). Four generations of flood management have been identified by Green *et.al.* (2000):

1. **Indigenous flood adaptation:**Settlements in flood-prone areas have developed some indigenous methods to protect against flooding, such as building houses on stilts above the anticipated flood level. These are effective for local, small-scale areas; however, experience shows they fail with modernization.
2. **Flood control and defense:** This generation of flood management dates back to the late nineteenth century and is known as the engineering approach; the

rationale was to stop riversfrom entering human communities. Strategies include flood control dams, embankments, flood defences, and channels. However, there are problems because this scheme may cause worse flooding downstream, create further flood plains, and damage the environment, and is likely to fail.

3. **Non-structural approaches:**The third wave was based on keeping people away from flood risk areas. Floodproofed buildings, insurance, and land use planning are some of the strategies proposed at this stage. Unfortunately, there are no sufficient knowledge and awareness of the difficulties in working successfully with this approach.
4. **Holistic approach:** flood mitigation has been replaced by flood control in terms of "coping with floods". Flood hazard management and flood risk management are the strategies introduced. Holistic catchment and coastal management, involvement of local communities, land use planning, response capacity improvement, and enhancement of flood disaster resilience are approaches taken at this level.

Increasing vulnerability, complexity, and uncertainty call for intergovernmental cooperation, in which three premises should be involved: first, the expansion of our knowledge in order to understand and forecast climate change and biophysical conditions, develop new techniques, improve the use of remote sensing data, etc.; second, vigilance in monitoring and assessing any human or natural changes; third, learning how to live in a dynamic system of humanity, biosphere and climate (Vlachos, 2010).

For constructive flood management it is of vital importance to learn how to do better; success and failure are both lessons. There are gaps between design/construction and operation/maintenance which need attention in an integrated management system. With both the previous points in mind, designing a dynamic risk management system through coordinated work is the best approach. On this basis, there are some schemes run by the Food and Agricultural Organization (FAO) and the Environment Agency:

i. Natural Flood Management (NFM) aims to minimize the amount of water reaching downstream and/or delay the peak of the flood in order to give more time for preparation. Some approaches taken in NFM plans are as follows (The Parliamentary Office of Science and Technology 2011):

1. Using ponds, ditches, land, or channels for water storage
2. Increasing soil infiltration
3. Slowing the flow of water
4. Reducing water flow connectivity

Catchment Flood Management Plans (CFMPs) are a planning tool through which the agency aims to work in partnership with other key decision-makers within a river catchment to explore and define long-term sustainable policies for flood risk management. CFMPs are a learning process to support an integrated approach to land use planning and management.

Planning Policy:This should require local planning authorities (SEMA and LEMC) to review the variation in flood risk across their jurisdiction, and to steer development away from areas at risk. Where this cannot be achieved and development is to be

permitted in areas that may be subject to some degree of flood risk, the planning policy shouldrequire the agencies to adopt a sequential approach that will minimize the risk of flooding that is posed to vulnerable land use. These Agencies must also demonstrate that there are sustainable mitigation solutions available that will ensure that the risk to property and life is minimized (throughout the lifetime of the development) should flooding occur. The following activities are promoted to control and manage flood risk in Nigeria (when there are adequate economic and environmental reasons) (NEMA, 2013):

1. Keeping and maintaining barriers and pumping stations
2. Clearing rivers
3. Controlling aquatic river weeds
4. Managing river embankments (e.g. trees, grass)
5. Repairing and maintaining flood defences
6. Maintaining river/ditch channels and banks
7. Consultation on new developments
8. Providing flood warnings.

There are a number of obstacles in the way of integrated, sustainable flood risk management (Greenet al., 2000):

1. Limited resource and investment
2. The absence of a definite list of flood zones, as there are a number of factors linked to the extent of floods, like weather, rainfall pattern, and topography.
3. Institutional limitations
4. Professional roles

5. The problem of importing solutions from outside the local system
6. Lack of knowledge and research
7. Lack of effective public involvement
8. Corruption

2.2.5 Emergency management

The global risk from natural hazards is increasing, as Figure 2.4 shows (CRED, 2011; Keogh et al. 2011). There was a dramatic increase in the number of disasters (the black line on the graph) and the number of affected people (the blue line) in the period from 1900 to 2010. However, thanks to technical improvements and mitigation, rescue, and preparedness strategies, the number of people killed has decreased.

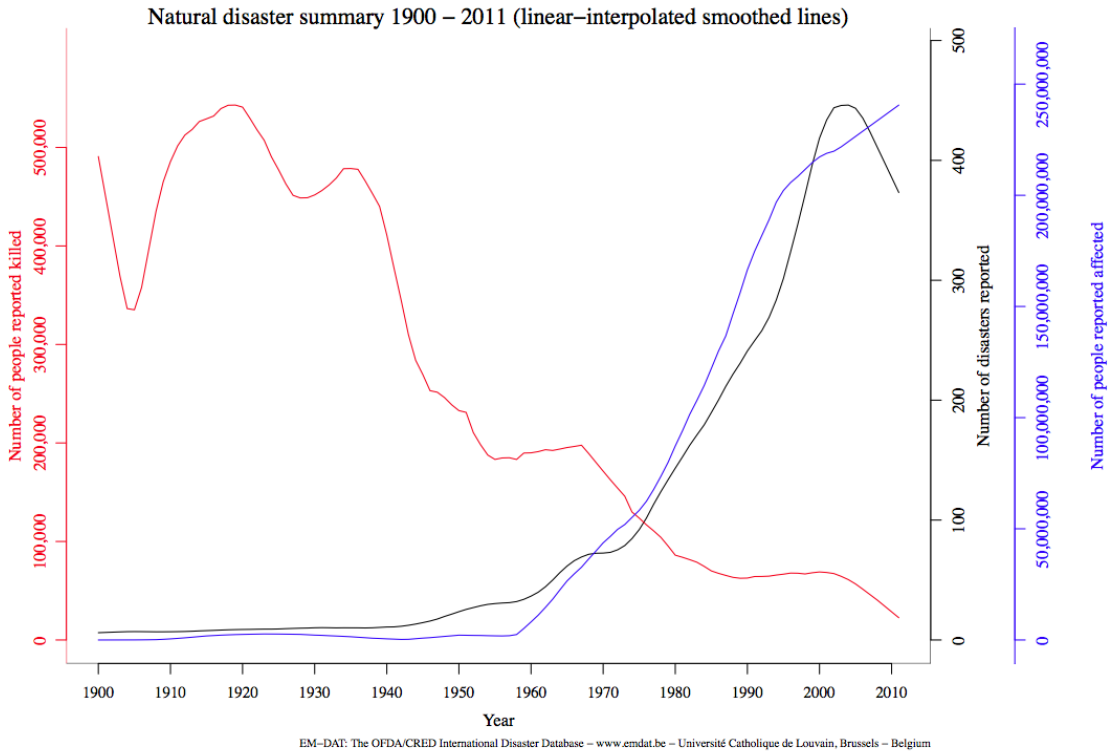


Figure 2. 3: Natural disaster summary (1900-2010)
Source: Adapted from Centre for Research on the Epidemiology of Disasters - CRED (2009)

The fact is, the reports on emergency events and their impacts on human life show apositive rate, and organizations all over the world have therefore made a great effort to move toward a more stable, steady situation if an extreme event should occur; NEMA (National Emergency Management Agency), UNISDR (The United Nations International Strategy for Disaster Reduction), CRED (Centre for Research on theEpidemiology of Disasters - CRED 2009), IDES (International Disaster Emergency Services), and WCDM (World Conference on Disaster Management) are examples of these organisations.

2.2.5 Disaster

The way we look at a concept explains the way it is defined, and the solutions we may think about (Weichselgartner, 2001). “Disasters are a result of the complex interaction between a potentially damaging physical event (e.g. floods, droughts, fire, earthquakes and storms) and the vulnerability of a society, its infrastructure, economy and environment, which are determined by human behavior” (Birkmann, 2006a).

Disasters have been a threat to nations, both economically and socially, and their economic impact is both local and global (Cutter,et al. 2003). Societies have attempted to reduce the extent of the losses inflicted by disasters with pre- and post-disaster activities, because disasters are large, rapid incidents which can affect many people. Their result and occurrence is uncertain and difficult to predict. They are rare, dynamic events, and their benefits, losses, and risks are difficult to assess (Committee on Planning for Catastrophe: National Research Council, 2007; Cutter,et al. 2003).

2.2.6 Comprehensive emergency management

Comprehensive Emergency Management (CEM), also named emergency response cycle or emergency management cycle (Drabek and Hoetmer, 1991; Committee on Planning for Catastrophe: National Research Council, 2007; Cutter,et al. 2003) demonstrates four phases in terms of pre- and post-disaster event activities, as shown in Figure 2.4.New approaches to CEM apply multi-dimensional methods to cover all four phases throughout the temporal and spatial dimension of the disaster events; CEM as the profession and skills of applying science and technology to manage and deal with disasters that can inflict enormous amounts of damage on nations (Drabek and Hoetmer, 1991; Committee on Planning for Catastrophe: National Research Council, 2007).



Figure 2.4: Comprehensive Emergency Management (CEM)

Source: Committee on Planning for Catastrophe: National Research Council, 2007

Preparedness is about getting ready before a disaster happens. It covers all theactivities that facilitate the operational capabilities, like public and staff training, data acquisition,

developing information and skills, and identifying the requirements. This phase helps to improve the efficiency and speed in the next phases, and even modelling the scenario of a disaster can provide a prior experience. Preparing the data sets and information all within one frame and also sharing them with all the organisations involved would make the preparedness phase much more productive.

The response and relief phase of CEM involves actions before, during and immediately after a disaster, when the main activities involve rescuing people in danger, restraining further destruction, and providing first aid. The rapid acquisition of data (including images) on the event and its geo-spatial dimension are critical in order to provide maps and reports for decision makers.The recovery phase involves short-term and long-term activities that return living conditions to their previous, normal level. This phase covers activities from foodprovision and sheltering (short-term) to reconstructing buildings (long-term). Geospatial data such as the location of hospitals, suitable places for temporary shelter, and provision of basic services and essential needs are important components for helping the decision makers to guide the recovery process. In addition, archiving the geospatial data in this phase can be very helpful in the preparedness and mitigation phases as well.

Mitigation is a long-term process that attempts to reduce the degree of long-term risk to society from hazards, with activities such as lessening vulnerability, developing risk maps and analysing them, identifying hazards, and introducing solutions to reduce the impact of forthcoming disasters to human life. Simulation models of disasters, comparing multiple alternatives for mitigation plans and visualizing the plans are some

of the geo-spatial activities in this phase (Committee on Planning for Catastrophe: National Research Council, 2007; Cova, 1999).

The mitigation phase is the one most cited by scientists as the main platform for disaster risk reduction activities as it focuses on the underlying factors of disaster scenarios. Weichselgartner (2001) suggested that the mitigation of natural hazards should concentrate on the human-related aspect rather than the hazard because we have no control over the physical part of a hazard. In addition, he stated that a proactive approach (rather than reactive), along with constantly modified policies and programmes which aim at the internal structure rather than the external sources, can significantly improve the mitigation phase.

Within the domain of mitigation activities, vulnerability is one of the most operative actions where it utilizes the geo-spatial data and analysis to develop a conceptual framework of all kinds of disasters in order to assess the resilience and predicted losses of the society affected. Therefore, a great deal of literature has marked it, attempting to develop up-to-date and more accurate methods.

2.2.7 Hydrologic modelling

Hydrological models are regarded as a powerful tool for predicting river basin response to rainfall events and assessment of impacts of parameters such as land-use cover change on river basin hydrology (Whitehead and Robinson, 1993). Hydrological modeling is a powerful technique of hydrologic system investigation for both the research hydrologists and the practicing water resources engineers involved in the planning and development of integrated approach for management of flooding. In recent

years hydrological processes in river basins have increasingly been studied in order to quantify the possible impacts of changes in land-use, land cover or soil surface conditions and urbanization on river basin hydrological processes, water quality and on extreme hydrological events such as floods and droughts. The main objective of these investigations was the development of concepts for sustainable river basin management. In this regard, experimental river basin studies as well as the application of hydrologic or eco-hydrologic models have been used.

In this research HEC-HMS4.0 is used as hydrological model. The Hydrologic Modeling System (HMS) is designed to simulate the precipitation-runoff processes of dendritic watershed systems. It is designed to be applicable in a wide range of geographic areas for solving the widest possible range of problems. This includes large river basin water supply and flood hydrology and small urban or natural watershed runoff. Hydrographs produced by the program are used directly or in conjunction with other software for studies of water availability, urban drainage, flood forecasting, future urbanization impact, reservoir spillway design, flood damage reduction, floodplain regulation, and systems operation (HEC-HMS, 2006).

Capabilities of HEC-HMS model can be mentioned such as the program has an extensive array of capabilities for conducting hydrologic simulation. Many of the most common methods in hydrologic engineering are included in such a way that they are easy to use. The program does the difficult work and leaves the user free to concentrate on how best to represent the watershed environment. On the other hand, such as every simulation system it has limitations due to the choices made in the design and development of the software. The limitations that arise in this program are due to two

aspects of the design: simplified model formulation, and simplified flow representation. Simplifying the model formulation allows the program to complete simulations very quickly while producing accurate and precise results. Simplifying the flow representation aids in keeping the compute process efficient and reduces duplication of capability in the HEC software suite (HEC-HMS, 2006).

The QUALHYMO, CUAHSI, HS, GHisMO, STORE DHM, MIKE URBAN, MIKE FLOOD and HAZUS HM are hydrological models that have capabilities to simulate rainfall run-off of drainage basins. These models can only operate in a gauged drainage basin with information on stream discharge for proper calibration but the HEC HMS as earlier mentioned is embedded with several methods that can operate in an ungauged drainage basin and also yield faster and more accurate results than the QUALHYMO and CUAHSI, HIS. Kano metropolis which is the study area has inadequate information on stream discharge and runoff, LULC and hence the need for use of HEC HMS.

2.2.8 HEC-HMS

HEC-HMS4.0 is a hydrological model developed by the Hydrologic Engineering Center of the United States Army Corps of Engineers. In 1968 HEC released the HEC-1 computer model to aid engineers in hydrologic analysis. The window-based HEC-HMS4.0 software was released in 1998. The program simulates a rainfall-runoff response of a river basin system to a precipitation input by representing the entire river basin as an interconnected system of hydrologic and hydraulic components, which include river basins, streams and reservoirs. The results from HEC-HMS4.0 model can be used as an input for hydraulic models.

The HEC-HMS4.0 software provides the following computational options to derive runoff response from rainfall-runoff process simulation: several alternatives for hydrologic losses determination lumped or linearly distributed runoff transformation methods, routing options and optimization system for calibration (HEC-HMS, 2006). HEC-HMS comprises of three main components for rainfall-runoff simulation; loss method, transformation method, base-flow method and routing method.

a. Loss Method

The term “Losses” refers to the amount of the rainfall from a storm event that is diverted from runoff, usually infiltrating to soil or flowing to other means of storage in the river basin system. The HEC-HMS4.0 model supports the most common methods for calculating losses, such as the initial/constant rates, Soil Conservation Services (SCS), Curve Number (CN) method and the Green and Ampt method. These methods can be lumped or linearly distributed throughout the model. In a lumped analysis, losses are spatially average over a river basin within the river basin, but for linearly distributed method, the rainfall is spatially defined for the entire river basin system, and losses are average for each river basin in the system.

This research applies the SCS method due to availability of related inputs data and also its reliable results. The SCSloss method is essentially a simplification of the comprehensive Richard's equation for unsteady water flow in soil. The SCS method assumes the soil is initially at uniform moisture content, and infiltration takes place with a so-called piston displacement. The method automatically accounts for ponding on the surface. One of the advantages of this method is that parameters can be estimated for an

un-gauged river basin from information about soil characteristics. The model computes the precipitation loss on the pervious area in a time interval.

b. Transformation Method

Runoff transformations convert the precipitation from a storm event, minus the losses, to direct runoff for each sub-river basin in the system. The runoff represented the hydrograph response at each sub-river basin outlet. Like the loss determination, the HEC-HMS4.0 software allows the modeler to determine the losses and direct runoff hydrograph based on lumped or linearly distributed approaches. In a lumped analysis, the direct runoff hydrograph is determined using unit hydrographs methods such as the Clark, Snyder or SCS hydrographs, or the Kinematic Wave method. In a linearly distributed method, for instance the Modified Clark hydrograph, the sub-river basins in the river basin system are spatially interpreted as numerous grid cells within a user-defined grid mesh, and the model computes the lag-time for excess rainfall to flow from grid cell to the river basin outlet. The hydrograph for the Modified Clark method is generated from the sum of the all the grid cell lag times for each sub-river basin in the system. This study adopted the use of SCS hydrographs due to its compatibility with the SCS loss method.

c. Routing Method

Routing is the movement of the runoff from the different watershed outlets throughout the system along the channel, and ultimately to the outlet or sink of the entire watershed system. The HEC-HMS4.1.0 model routing options include the Muskingum, Modified Puls, Kinematic Wave, and Muskingum-Cunge methods. Hydraulic models do not

always model the entire stream network used in a corresponding hydrologic model. Some modelers may further refine the study area to a smaller range. In such cases, the routing methods provided in HEC-HMS4.1.0 software can provide flow hydrographs at locations known as junctions along the stream network of a system. This provision can compensate for discontinuities between the two models by providing upstream and downstream boundary conditions for the further refined hydraulic model (Snead, 2000).Each of routing models computes a downstream hydrograph, given an upstream hydrograph as a boundary condition. Each does so by solving the continuity and momentum equations. The basic information requirements for all routing models are described below:

i. **A description of the channel:** All routing models that are included in the program require a description of the channel. In some of the models, this description is implicit in parameters of the model. In others, the description is provided in more common terms: channel width, bed slope, cross-section shape, or the equivalent.

ii. **Energy-loss model parameters:** All routing models incorporate some type of energy-loss model. The physically-based routing models, such as the kinematic-wave model and the Muskingum-Cunge model use Manning's equation and Manning’s roughness coefficients (n values). Other models represent the energy loss empirically.

iii. **Initial conditions:** All routing models require initial conditions, the flow (or stage) at the downstream cross section of a channel prior to the first time period. For example, the initial downstream flow could be estimated as the

base-flow within the channel at the start of the simulation, as the initial inflow, or as downstream flow likely to occur during a hypothetical event.

iv. **Boundary conditions:** The boundary conditions for routing models are the upstream inflow, lateral inflow, and tributary inflow hydrographs. These may be observed historical events, or they may be computed with the rainfall-runoff models included in the program (HEC-HMS, 2006).

2.4 Vulnerability

In recentyears, more attentionhas been paid to the conceptofvulnerability. Although theconcept ofvulnerabilitywasfirstperceivedasuncertain, ill-definedandwide,it hasshed a light on clarificationinthecontextonrisk, hazard anddisaster management andseparationoftheconcepts.HistoricallypeoplewouldthinkofanactofGod,luck, orfortunewhenconsidering theissuewecallrisktoday(Weichselgartner andBerten 2000).Vulnerabilityisaninternalcomponent ofriskwhich helps us in disaster management.Itexplainsthecharacteristicsofa system feasible to the damage of an event (hazard) (Cardona, 2003; Cannon *et.al.* 2004; VillagrándeLéon, 2006).

Everybody is vulnerable to some degree (Anderson, 1995; Cannon *et.al.,* 2004). However, the task is to determine who and what are vulnerable, to what and where. These facts help us to make decisions on the actions required in risk management. Fundamentally, we assess vulnerability levels in the system to assist in reducing the effects of disasters. Vulnerability is a relational term whichshould be rethoughtpro-actively in compound, interactive, and complex systemboth qualitatively and quantitatively (Weichselgartner, 2001; Kasperson et al. 1995; Green and Penning-Rowsell, 2007). Comprehensive Approach for Probabilistic Risk Assessment is an

example of such an attempt (CAPRA),2010) in the discourse of vulnerability language. Individuals use language purposefully to persuade others on an action. They make use of language to define a framework of vulnerability which gives a specific insight into the problem. The way a problem is defined determines where we look for solutions and the tools we design for action (Weichselgartner, 2001; Green and Penning-Rowsell, 2007). Therefore, it is importantto understand the nature and purpose of language when we discuss vulnerability.

2.4.1 Definitions of vulnerability

Vulnerability is the conditions determined by physical, social, economic and environmental factors or processes, which increase the susceptibility of acommunity to the impact of hazards (UNISDR, 2004).

Green (2004) states that we can discuss the concept of vulnerability without sharing the same definition. However, to assess vulnerability we need to have a clear understanding of the concept. Vulnerability is a multifaceted and relational term; some scientists have even stated that it cannot be defined without specification ofthe hazard, system, interactive environment, and temporal dimension (Brooks, 2003; Methods for the Improvement of Vulnerability Assessment in Europe (MOVE), 2008). Any definition of vulnerability promotes an understanding of the world and gives us an insight into the nature of the problem. Stakeholders have defined vulnerability from diverse points of view, compatiblewith the goals and objectives they follow (Green, 2004; Birkmann, 2006b; Penning-Rowsell, et.al. 1992).

It is not possible and more importantly not beneficial to unify definitions of the term

‘Vulnerability’, for the reason that there are concepts, natures, and purposes embedded within each definition.However, it is important to state what one meansin a research studywhich includes vulnerability. Thereason is the variety of choices which need to be taken: methods and factors which will be used and tools which will be thoughtof for vulnerability reduction. For thepurpose of this research thedefinition given above has been chosen.

2.4.2 The history of vulnerability

Thediscussion of vulnerability requires a clear understanding of the origin of the concept. In total, three origins of vulnerability assessment have been distinguished: social, physical, and socio-physical (the vulnerability of places).Vulnerability research canbe traced through social science,where it has its roots in the analysis of risk reduction anddisaster resilience (Cardona, 2003; Blaikie, et al. 2004; Birkmann, 2006b). In this way, hazard has been seen as a passive factor from an external source, while vulnerability is a dynamic internal characteristic of the system. In social science, vulnerability has been seen as a tempered response to hazardous events where concepts such as resilience and coping capacity in a human system are considered. Social vulnerability studies the social aspects of vulnerability, such as cultural,historical, and global change, and economic features (Liverman, 1990;Adger, 1999; Bohle, 2001; Green, 2004;Downing*et.al.* 2006; Cutter and Finch, 2008).

Physical vulnerability has its roots in geography and natural hazard analysis (Fussel, 2007). The human system has been taken as a passive factor, modifier to disaster damage withleast attention, while hazard plays the active role. In this approach, vulnerability is perceived as a pre-existing condition determined by exposure and

hazard. Indicators such as hazard zone, distribution, impact, human occupancy, duration, distribution of losses, magnitude, frequency, and quickness have been utilized (Griffith, 1986; Godschalk, 1991; Pelling and Uitto, 2001; Sanyal and Lu, 2004; Sanyal and Lu, 2005; Ip, et al. 2006; Sophiayati, and Vladimirova, 2009).

There is a third approach to vulnerability that considers it as an interaction between human and biophysical systems, where vulnerability is defined as acombination of biophysical hazard and social response within a geographic area. This method takes social and physical indicators, but explicitly emphasizes the geography of the place, which is why the method is famous as the study of vulnerability of places. This methodologyhas been applied to spatial environments including local, regional, national, and international spatial contexts (Penning-Rowsell, et al.,1992; Cutter, 1996; Cutter, et al. 2000; Smith, 2000; Weichselgartner, 2001; Turner et al.2003; Wei, et al.2004; Downing, et al.2006; Berkes, 2007; Methods for the Improvement of Vulnerability Assessment in Europe (MOVE), 2008; Roberts, et al. 2009; Jakibicka, et al. 2010).

2.4.3 Characteristics of vulnerability

Vulnerability reduction is the first step towards a disasterresilient society. A great deal of literature has emphasized the interactive nature of vulnerability (Anderson, 1995; Downing, et al. 2006; Birkmann, 2006c; Naude, et al. 2009). Birkmann has clarified in his book that “vulnerability is a complex interaction between a potentially damaging physical event and the vulnerability of the society” (Birkmann, 2006c). Multi-dimensionality, differentially scale dependency and dynamics are the three chief characteristics of vulnerability mentioned by great many studies (Adger, 1999;Vogel

and O'Brien, 2004; Downinget al, 2006: Birkmann, 2006b).

In addition, some scientists have insisted that vulnerability cannot be assessed without clearly specifying the hazard type, system, variables of concernand temporal frame (Brooks, 2003; Metzger, et al. 2005; Fussel, 2007).Downing and colleagues (2006) distinguished several features of vulnerability differential exposure to stress a dynamic process withinter linked time scales, multiple attributes of human actors, multiple scales, and inherent.

Furthermore, Anderson (1995) put forward a list of vulnerability characteristics which is still worthy ofconsideration:

1. **Complex:** vulnerability is a complex and multi-faceted concept. Several factors fromdifferent settings contribute in shaping vulnerability, which is therefore specific to location, target group and context.
2. **Dynamic:** Vulnerability is a result of interaction between social and environmental systems. Because factors contributing to vulnerability are always changing, vulnerability changeover time swell. Designing model whichtracks the direction and magnitude of vulnerability change is beneficial.
3. **Cumulative:** People who have experienced a disaster are often left more vulnerable tofuture hazardous events. This is because they will not have the same level of resilience owing to theloss of some resources.
4. **Self-compounding:**Factors shaping vulnerability are inter-related. Therefore when a group is vulnerable because of poverty it is likely to be vulnerable because of health or lack of education.
5. **Irreversible:**some causes of vulnerability are rooted in natural

resources.Degradationoftheseresourcesresultsinincreasingvulnerabilitywhichisoften irreversible.

6. **Borderless:** environmental hazards cannot be contained or limited to borders.

2.4.4 Causes of vulnerability

As people gain more experience and knowledge in disaster risk management, theyhave to acknowledge the complex and interconnected nature of vulnerability. Vulnerability is intrinsically tied into various social and environmental processes. Cardona,et al.(2003)believes that vulnerability has its roots in economic, demographic, environmental, and political practices that distribute resources among groups. In addition, some global trends such as population growth, urban change, global warming, war, and climatechange, and international financial pressure should be considered. Other grounds for vulnerability can be traced through physical fragility and exposure to the sources of hazardous events (i.e. unsafe location, non-resistant physical infrastructure), socio-economic weaknesses and susceptibility and lack of resilience (i.e. limited access incapacity to respond).

Despite all thenew technologies, economic progress and social development, the vulnerability of societies to hazards is increasing. The widening gap between poor and rich, the thought that rationality can be gained by pricing, the feeling that everything can be done higher expectations, urbanization, suburban expansion, population growth, invention of dangerous techniques, and production of litter and waste are the main trends related to increased vulnerability (Anderson, 1995).

2.4.5 Vulnerability Dimensions and Factors

Bogardiand Brauch (2005) havedelineated a model which shows the widening concept of vulnerability (Figure2.5). Almost every researcher agrees vulnerability is the internal side of risk. Some scientists have defined vulnerability as a characteristic of the elements at risk (Davidson, 1997; Cardona, 2003; Blaikie et al. 2004; Cardona, 2011).Forinstance, Blaikie et al.(2004) say that vulnerability arises from system-specific factors such as economic imbalances disparity in power among social groups'knowledge dissemination and social protection. They found factors of vulnerability in the ability of systems to cope with, mitigate and recover from the impacts of disasters. Another example can be seen in Cardona (2003) where he states that vulnerability is tied to social and physical processes. From Cardona's point of view, vulnerability is a result of system fragility, susceptibility, and lack of resilience. He emphasises that those political, economic and demographic processes that distribute resources among groups of people are the basic roots of vulnerability. The following dimensions of vulnerability have beencited: economic political, social, physical, environmental, institutional, educational, cultural, and ideological (Wilches-Chaux, 1993; VillagrándeLéon, 2006; Methods for the Improvement of Vulnerability Assessment in Europe (MOVE), 2008; Cardona, 2011).

A second way of looking at vulnerability defines it as the likelihood of injury, disruption, and harm. Here, the main elements of vulnerability are conditions which increase the chance of injury (Gabor and Griffith, 1979; Godschalk, 1991; Anderson, 1995; Cutter, 1996; Adger, 1999; Wisner, 2002; Downing, *et.al.* 2006; Gallopin, 2006).

The thirdapproach is dualistic,where vulnerability is a result of interaction between

system's susceptibility to external harm and its internal coping capacity to recover from the impacts of thedisaster (Bohle, 2001; Pelling, 2003; Renaud, 2006; Berkes, 2007).

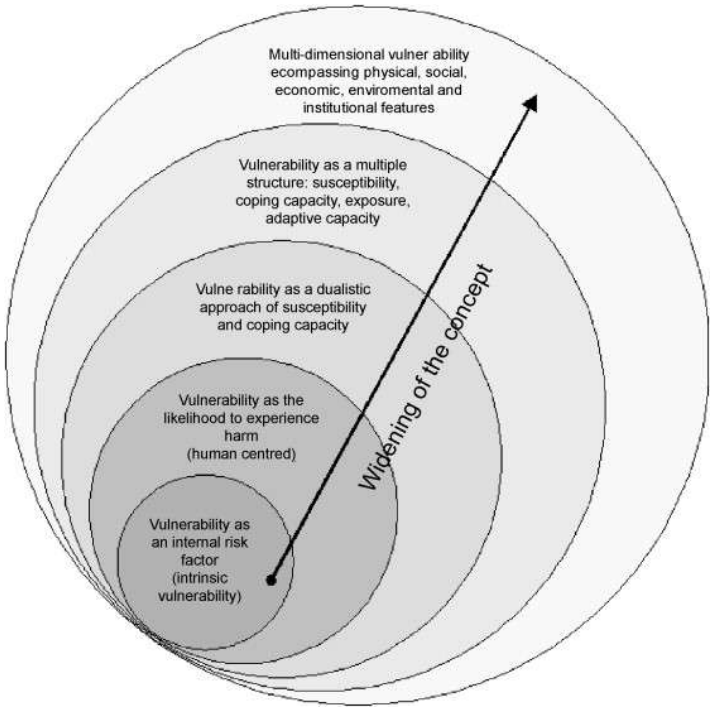


Figure 2.5: Spheres of the Concept of Vulnerability
Source: Adapted from Birkmann (2005)

The next step is to understand the multifaceted nature of vulnerability.Therefore, it is not just the coping capacity and susceptibility of the system which determine vulnerability; factors such as exposure, adaptive capacity, and interaction with stress are also considered (Weichselgartner, 2001; Turner, et al. 2003).

The most comprehensive approach can be seen in the definition of UNISDR, which shows notonly the multifacet nature of vulnerability but also the variety of dimensions which have been set for it (UNISDR, 2004; Birkmann, 2006c; Fussel, 2007). In this way, vulnerability is seen as exposure, adaptive and coping capacity, andthe susceptibility of the system and external stress in a multi-dimensional environment;

physical, environmental, social andeconomic.

Havinginmindalltheaboveapproachesto theextent ofvulnerability concept, relative factors indicators anddimensionshavebeenproposed.Forexample,Cardona(2011) regards vulnerability as an intrinsic property of the elements at risk, butatthe same time defines a number of dimensions of vulnerability: physical, environmental economic, social, political, institutional, educational, cultural andideological. Adger(1999) belongs to these condition circles in Figure 2.5; he distinguishes two levels ofassessment: individual and collective. Weichselgartner(2001) (from thefourthcircle) mentions hazard, exposure, preparedness, prevention, andresponses as the factorsofvulnerability.The dimensionsofvulnerability havebeenunderstoodby Fussel (2007) as the temporal sphere, knowledge domain, system, hazard, and attribute of concern (Fussel, 2007). Whateverthe indicators and factors of vulnerability with regard tothe approach and perspective of the researchthere are issues to be well thought out (Naude, et al. 2009):

1. Act as a predictive quality,
2. Explain vulnerability in relation to a socially accepted level of results,
3. Give an insight into the causes of vulnerability,
4. Hazard specific,
5. Appreciate dynamic nature of vulnerability and
6. Introductionof copingtools.

2.4.6 Vulnerability frameworks

In this section some of the most fundamental and well-known frameworks of

vulnerability will be discussed. These have been proposed by experts from diverse perspectives and disciplines. Birkmann (2006b) has put forward six schools of thought in vulnerability assessment. This proposal has been adopted to describe the vulnerability frameworks in more detail based on the understanding and review of the author.

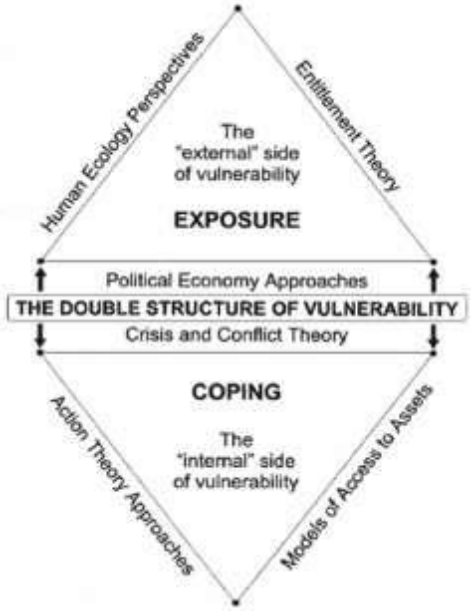


Figure 2.6: Vulnerability Framework
Source: Adapted from Bohle, 2001

First is the double structure of vulnerability. Bohle (2001) defines vulnerability as the internal factors of the system such as the ability to anticipate cope with resist and recover fromthe disadvantageous effects of the disaster and an external factor which is exposure to risk and hazard (Figure 2.6). In this school of thoughtthe frame work proposed by Gabor and Griffith (1979) can also be mentioned. They assessed vulnerability on two scales: large geographic entities (e.g. states) and local disaster planning (e.g. metropolis). In their perspective vulnerability is defined as the result of hazard risk and system preparedness (Gabor and Griffith, 1979). The sustainable

livelihood model is another contribution in this school of thought (Chambers and Conway, 1992).

The second approach is the analysis of vulnerability within a hazard and risk framework. In this school, vulnerability is seen as an element participating in risk, where risk is generally seen as a result of hazard exposure, vulnerability, and coping capacity (Davidson, 1997).

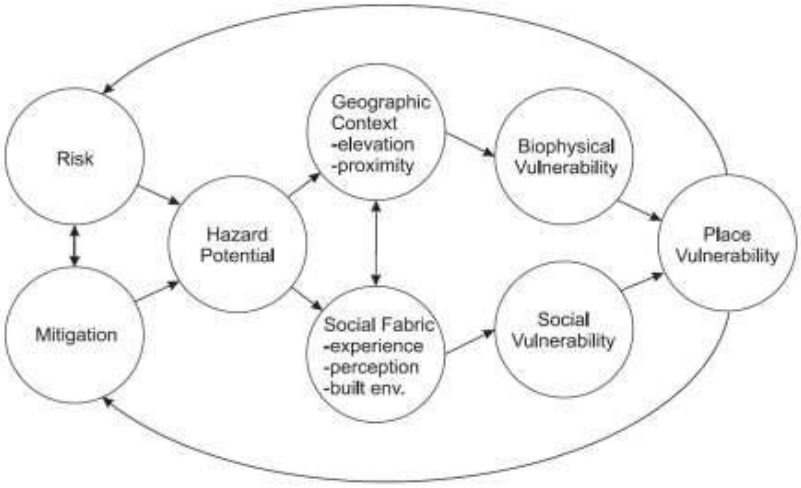


Figure 2.7: Cutter's Framework of Vulnerability
Source:Adapted from Cutteretal (2003)

Weichselgartner (2001) describes vulnerability as a combination of a pre-existing condition (physical vulnerability) and tempered response (social vulnerability) within setofgeographicconditions.Heintendsvulnerabilityanalysistocontribute towards disaster damage reduction. In the USA Cutter (1996) made an attempt to develop a conceptual framework with regards to hazard mitigation strategies considering interaction between nature, society andtechnology with an explicit focus on the locality of analysis. She also considered vulnerability as a result of interaction between social and biophysical elements (Figure 2.7).

In addition, Brooks (2003) introduced the concept of adaptive capacity in the school of disaster risk reduction. Furthermore, Roberts and colleagues developed an especially interesting model of vulnerability in the context of a natural science paradigm.They highlighted the importance of scale in vulnerability analysis and took advantage of both social and biophysical parameters (Roberts, et al.2009).

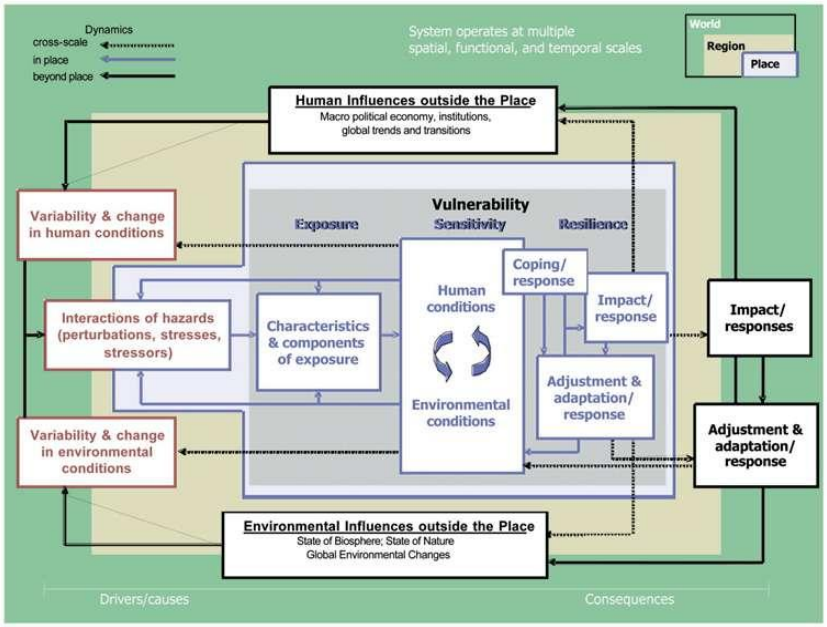


Figure 2.8: Turner's Conceptual Model
Source:Adapted from Turneret al (2003)

The third school is global environmental change where vulnerability and risk are seen in the broad global context and notions such as global environmental change are respected (Liverman, 1990; Adger, 1999). As Figure 2.8 demonstrates Turner et al(2003) developed complex vulnerability framework which sets in global environmental change community. In their framework vulnerability is defined as a coupled human–environmental systemcomprising exposure, sensitivity, coping response, impact response and adaptive response (Turner, et al 2003). Recent work in this school is by Fussel (2007), who clearly discriminated between existing conceptual

models and offered a newframework for global environmental change society. Hestated that for vulnerability analysis we need to be specificabout the system in question, hazard type attribute of concern and temporal reference.

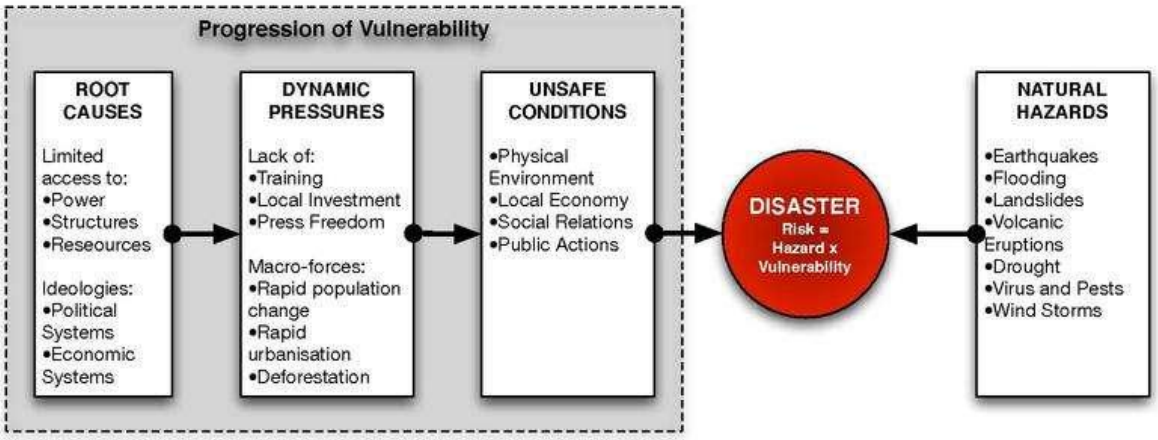


Figure 2.9: Pressure and Release (PAR) Model
Source:Adapted from Blaikie, et al (2004)

The fourth school is political economy. One of the best-known vulnerability frameworks, Pressure and Release (PAR)belongs to this school of thought (Figure 2.9). Blaikie and colleagues defined disaster as a result of two sources of pressure: a natural hazard and a vulnerable situation. The PAR model is based on thecommon risk module.

Risk=Hazard x Vulnerability……. Equation 2

This model illustrates how a disaster forms when natural hazards strike vulnerable people. Inthis model, vulnerability consists of three progressiveprocesses: root causes, dynamic pressure and unsafe conditions. Basically, in this framework they look forvulnerability reduction in a change in the political and economic system. Another example from this school is the sectoral approach by Villagrán De Leon

(2006). He developed asimplified model of vulnerability for policy makers using a quantitative weighting system. Three pillarswere set for vulnerability: geographical level, sector level and components level.

The fifth school is the holistic approach to risk and vulnerability assessment. As Figure 2.10 shows, this framework emphasizes the dynamic (time dependent)complex and multi-dimensional nature of vulnerability studies. Two categories of risk have been defined within the concept of vulnerability: hard risk, which is hazard-dependent, and risk, whichis non-hazard-dependent. Hardrisk consists of exposure and physical susceptibility. Soft risk comprises socio-economic fragilities and lack of resilience (Cardona, 1999; Cardona, 2003; Methods for the Improvement of Vulnerability Assessment in Europe (MOVE), 2008; Cardona, et al2010; Cardona, 2011). In addition, Carreno et al(2005) expanded a revised version of the holistic approach in seismic risk reduction.

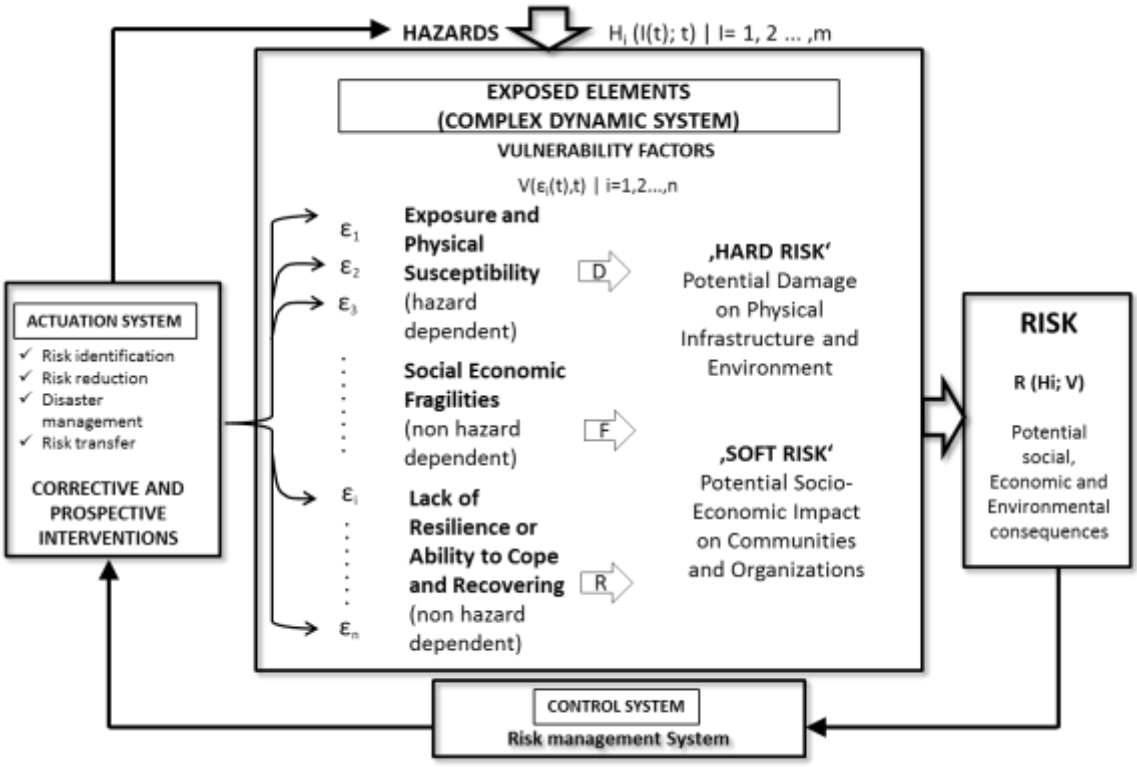


Figure 2. 10: The Holistic Approach to Disaster Risk Management
Source:Adapted from Cardona, 2003

The fifth and last school of thought proposed by Birkmann et al(2006) is the BBC (Bogardi and Birkmann, 2004; Birkmann, et al 2006; Birkmann, 2007). This model is based on works by Bogardi and Birkmann (2004) and Cardona (1999). It makes use of elements from other framework that aimsat vulnerability reduction andunsustainable development. Exposed/susceptible elements and coping capacity as the main factors of vulnerability and the threepillars of sustainability (environmental, economic, and social) are the main theme of this model (Figure 2.10). The authors declare that understanding of vulnerability should go beyond damage reduction. They initiated intervention systems as a vulnerability reduction tool (Birkmann, et al 2006).

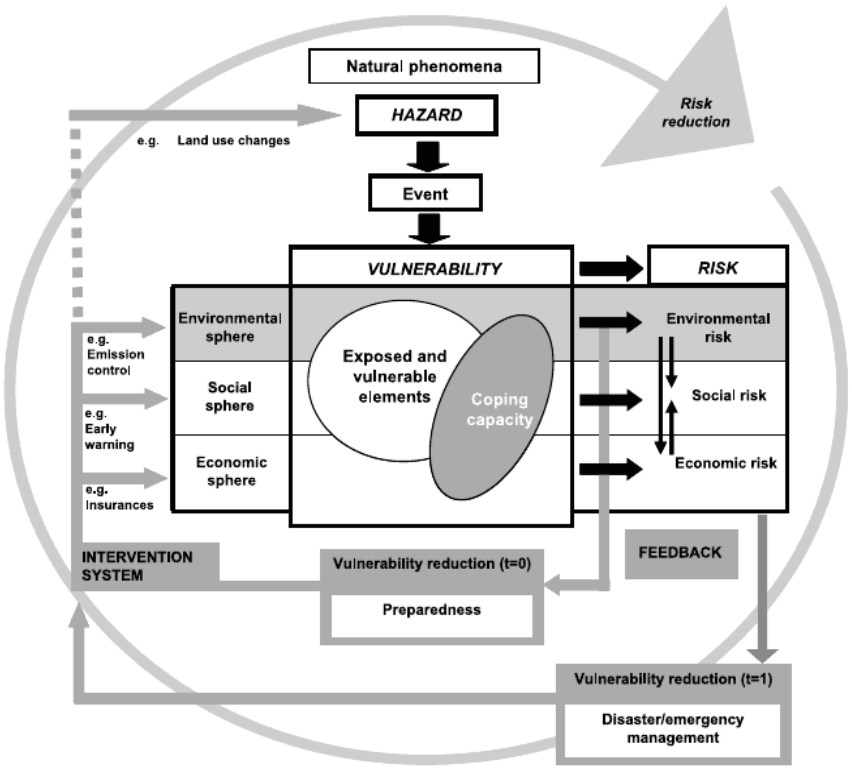


Figure 2.11: BBC Framework
Source:Adapted by Birkmann, 2006b

2.4.7 Classification of vulnerability methodologies

There are great numbers of vulnerability frameworks associated with methodologies for assessing and measuring vulnerability. There is no need to unify the concept of vulnerability and in fact it's not feasible to doso because specialist have reviewed and considered it according to their perspectives and goals.However, Anderson (1995) states that a framework should be simple enough to grasp,complex enough to capture the reality comprehensive enough to capture all the critical factors for understanding the roots of vulnerability and able to picture essential relations and interactions between factors. Turner *et.al.* (2003) explained some ways to improve vulnerability analysis:

1. Considering vulnerability in a coupled human-environmental system
2. Identification of the complexity, inter-connectedness and interactive nature of

components

3. Reflection on the location and scale of theproblems
4. Detection of dynamics within the human-environmental system which give rise tonew hazards
5. Recognition of critical interactions in the system that suggest response opportunitiesfor decision makers
6. Openness to both qualitative and quantitative analysis
7. Assistance in the development of metrics andnew models.

There is a fascinatingclassification of vulnerability methodologies presented by Birkmann (2006a) whichwill be used as the basis of the following discussion. The first tissue is quantitative versus qualitative approaches. Infactdeciding whetherto use qualitative or quantitative methods depends on the focus and scale of the approach. Examples of qualitative approaches are (Weichselgartner, 2001; Luers, 2005; Wisner, 2006; Naudeetal.2009) and examples of quantitative approaches are (Pelling, 2006; Peduzzi, 2006).

Secondlywe may classifythe methods as hazard-specific or hazard-independent. Some scholars insist that vulnerability assessment should be holistic and should aim at preparedness for multiple hazards. Decision making and policies need to be based on a multi-stressor situation (Cutter et al. 2003; Pelling, 2006; Greiving, 2006; Methods for the Improvement of Vulnerability Assessment in Europe (MOVE), 2008). In contrast other scientists believe that vulnerability is a characteristic of apacific hazard and should be validated with regard to the factors of relatedhazard situation (Brooks, 2003; Metzger et al. 2005; Downing et al. 2006; Illagrándeléon, 2006; Fusel, 2007).

Thirdly, global assessment may be evaluated in comparison to local assessments. Global analyses give us an overview and method of comparison for countries worldwide (Turner et al. 2003; Dilley, 2006; Cardona, et al. 2010). However such analyses have revealed that countries should be assessed with regard to their characteristics. For example, developing countries have higher numbers of people killed or injured while developed countries have higher economic losses, which shows that indicators thatdetermine vulnerability vary among nations. Therefore context-specific approacheswhich considerthe importance of time and scale may produce better results (Gabor and Griffith, 1979; Adger, 1999; Brooks, 2003; Dixit, 2003; Luers, 2005; VillagrándeLéon, 2006; Fussel, 2007; Roberts, et al.2009).

Fourthly, there is the question of whether to use reliable losses fuzzy context interpretation. Some methods use the losses and damage experienced and recorded to assess vulnerability (Pelling, 2006; Peduzzi, 2006; Dilley, 2006) implying a retrospective viewwhile the alternative way is a forward-looking assessment using broader perspective indicators such as population growth or literacy rate (Carrenoet al.2005; Birkmannet al., 2006). Points to bear in mind are, firstly, that not all historical datasets are reliable and secondly, that some of the indicators of vulnerability are really important for revealing the pattern of vulnerability in society.

The fifth issue is the notion of a simplified or complex framework. Anderson (1995) has mentioned that a framework should be simple enough to be understandable and complex enough to capture the reality. This is one of the major issues for every specialist in developing a model. For quantitative approaches having a simple model is beneficial in order to take measurements and to avoid mistakes. In additionthe scale of

the approach plays a role in how complex a framework can become. For global approaches there are not many data sets available. Furthermore, the thematic scope and focus of the approach determine the level of simplification (Baltic et al. 2009).

Finally, the importance of having goals and targets for a vulnerability assessment should be noted. It is proven that efficiency of analysis and reliability of results will be dramatically improved by establishing a set of goals for analysis through the use of FVIs.

2.4.8 Vulnerability and other related terms

In this section, theconcepts which are related to vulnerability and are often misunderstood or confused with vulnerability are clarified and their working definitions are stated. It is of essential importance to be clear about the terms which will be used in this to prevent any distortion.

2.4.8.1. Vulnerability and hazard

Hazard is the starting point for disaster risk reduction and sustainability. A variety of definitions have been offered for‘hazard’ (UNISDR, 2002; Cardona, 2003; Ologunorisa, 2004; Birkmann, 2006; Methods for the Improvement of Vulnerability Assessment in Europe (MOVE) 2008; Roberts et al. 2009; Cardona, et al. 2010). However, in this context ‘hazard’ is defined as: “A potentially damaging physical eventphenomenon and/ or human activity, which may cause the loss of life or injury property damage, social and economic disruption or environmental degradation.”(UNISDR, 2002).

Hazard has a socio-natural origin and is defined generally as the potentiality of a particular threatening event occurring during a particular period. Hazard is often seen from the risk reduction perspective and is a factor of risk (Equation 2.1). Hazards are characterized indicators such as location magnitude frequency, probability, depth, duration, and velocity (Ologunorisa, 2004; Methods for the Improvement of Vulnerability Assessment in Europe (MOVE), 2008).In additionthe Centre for Research on the Epidemiology of Disasters (CRED) (2011a) mentions that hazard is a totally different concept from disaster. Hazard is defined as: "threatening event or probability of occurrence of a potentially damaging phenomenon within a given time period and area" (CRED, 2011b). In the context of this study is regarded as peak discharge of flood water.

2.4.8.2 Vulnerability and disaster

"Instead of defining disastersprimarily as physical occurrences requiring largely technological solutions disasters are better viewed as a result of the complex interaction between a potentially damaging physical event (e.g. floods droughts, fire, earthquakes and storms) and the vulnerability of a society its infrastructure economy and environmentwhich aredetermined by human behavior."(Birkmann, 2006c).

In addition(CRED, 2011a) has made a glossary of all the terms related to disasters. It has defined disasters as "a situation or event, which overwhelms local capacity, necessitating a request tonational or international level for external assistance; anunforeseen and often sudden event that causes great damage, destruction and humansuffering. Though oftencaused bynature, disasterscan have human origins. Wars and civil disturbances that destroy home lands and displace people are included among

the causes ofdisasters. Other causes can be: building collapse, blizzard, drought, epidemic, earthquake, explosion, fire, flood, hazardous material or transportation incident (such as a chemical spill), hurricane, nuclear incident, tornado, or volcano."

Infact, numerous scholars have emphasized the fact that disasters are not just natural events,but that the social context should also be counted (Anderson, 1995; Weichselgartner and Berten, 2000; Weichselgartner, 2001; Cardona, 2003; Blaikie, et al.2004; Cardona, 2011). Blaikie et al.(2004) explained that disasters are the result of risk and vulnerability.

2.4.8.3. Vulnerability and risk

"The term risk encompasses the probability and the amount of harmfulconsequences or expected losses resulting frominteractions between natural or human induced hazards and vulnerable conditions."(UNISDR, 2002). Even though some people use the term 'risk' when they are referring to vulnerability orhazard, there is a difference between the terms. In the briefestcase, risk has been defined as the threat of hazards (Gabor and Griffith, 1979) or the physical characteristics ofthe hazardous event (Blaikie*et.al.* 2004). However, most scholars regard it as a hazard and its consequences (Kron, 2005; Birkmann, 2007). Risk, vulnerability and hazard are intertwined tocreate the damage and losses caused by a disaster; therefore, an understanding of the risk ofdisaster can greatly improve policy planning and the tools we apply for damage reduction (Blaikie *et.al.* 2004; Cardona*et.al*, 2010).

In addition risk is the "expected losses (of lives, persons injuredproperty damaged and economic activity disrupted) due to a particular hazard for a given area and reference

period. Based on mathematical calculations risk is the function of hazard and vulnerability(Achilleos, 2005). The United Nations Disaster Relief Co-ordinator (UNDRO).

Risk = R(HCE_h) V (Ev)

Risk = R (H (E_h). V (E_v))……. Equation 2.2

Where hazard is a function (H)derived from hazard elements (E_h), vulnerability is a function (V) derived from vulnerability elements (E_v) and risk is a function (R)derived from the results offunctions (H and V).

Cova (1999) describes the difference between vulnerability andHazard as the inherent classification of the human/physical environment.However, later studies on vulnerability consider both social and bio-physical indicators at specific places and applications (Weichselgartner, 2001; Cutter *et.al.* 2000). An example of the formula above can be found in the work by Chung *et.al. (*2005). they have designed a three-step procedure and software to support the model for decision makers. At the first step, a potential hazard map is constructed,while the second step is about validation of the probability of occurrence of each hazard level. Finally, a risk map can be generated bycombining hazard prediction and socio-economicfactors (Chung *et.al.*2005).

Risk is generally accepted as the interaction of physical hazards and social vulnerability (Cardona, 1999; Cardona, 2003; Brooks, 2003; Ologunorisa, 2004; Birkmann, 2005; Birkmann, 2007; Roberts *et.al*. 2009; Cardona *et.al.*2010; Cardona, 2011).Consequently there is no risk where a natural hazard occurs in a place with no exposed values. Kron (2005) provides a broader definition where hestates that risk is a

function of hazard values at riskand vulnerability.

2.4.8.4. Vulnerability and coping capacity

"Coping capacity is acombination of all strengths and resources available within a community or organization that can reduce the levelof risk, or the effects of a disaster." (UNISDR, 2002).

Coping capacity emerged from the discourse on vulnerability where scholars realized that vulnerability is more than exposure, susceptibility, and sensitivity, but also includes the capacity of the system to cope with disaster (Chambers and Conway, 1992; Cardona, 1999; Bohle, 2001; Cutter, *et.al.*2003; Dixit, 2003; Blaikie *et.al*. 2004; Carreno *et.al.* 2005; Birkmann, 2006c; MOVE, 2008).Therefore, coping capacity has been seen as a subcomponent of vulnerability, although it has been acknowledged that distinguishing between indicators is problematic (Roberts,*et.al.* 2009).

It is noteworthy to mention a different concept named 'adaptive capacity' (Intergovernmental Panel on Climate Change (IPCC), 2001; Brooks, 2003; Adger *et.al.*2004). Adaptivecapacity can reduce social vulnerability and hence the disaster risk. It has been defined as the "ability or capacity of a system to modify or change its characteristics or behaviors so as to cope better with existing or anticipated external stresses" (Brooks, 2003). The adaptive capacity of ahuman system represents the potential of the system to reduce its social vulnerability and thus to minimize the risk Associated with a given hazard.

2.4.8.5 Vulnerability and Resilience

"Resilience describes the capability of a system to maintain its basic functions and structures in time of shocks and perturbations and cancontinue to deliver resources and ecosystem services that are essential for human livelihoods."(Birkmann, 2006a). This is a general definition of resilience but there are various perceptions of the term where somedefine it as the opposite of vulnerability and lack of human security (Adger *et.al*., 2005; Bogardi and Brauch, 2005). In addition resilience could be related to the concepts of coping and adaptation. Resilience is a characteristic of a system which is desirable among the decision making and management practices where the aim is for vulnerability reductionanddisasterresilientsocieties.

2.4.8.6 Vulnerability and Sustainability

“Sustainable development is development that meets the needs of the present withoutcompromising the ability of future generations to meet their own needs.” (World Commission on Environment and Development, 1987). Concepts of sustainability and vulnerability are interconnected. Sustainable development is not possible without explicit policies to reduce vulnerability, and vulnerability reduction is not achievable without approaches to sustainable development (Anderson, 1995). The increasein the number of disastersand the number of extreme events worldwide, higher vulnerability of societies, global environmental changes, natural resource degradation and the rise in human and economic losses dueto disasters are some of the warnings calling for vulnerability and risk reduction which aims at sustainable development.

Birkmann (2006b) has made an interesting description of sustainability in his book where he has comprehensively introduced two schools of thought on sustainability: The Triangleof sustainability (Serageldin, 1995) and the Egg of sustainable development (Busch-Luty, 1995).

2.5 Flood Vulnerability Index System

The FVI system can be used as an instrument to link a multidisciplinary subject with a large number of components in a straight way and can also provide a good review of vulnerability in three scales include: River basin, sub-catchment and urban area. This system helps decision makers to control the possible damages and distinguish the precise measures for implementing before flooding (Balica and Wright, 2010). The Flood Vulnerability Index can be used in action plans to manage flooding and can improve local decision-making practices with appropriate measures to reduce vulnerability in different spatial levels (Balica *et.al.*, 2009). Parameters and indices should be designed to produce information for specific target areas.

2.5.1 Development of Flood Vulnerability Index Methodology in Urban Area

Urban areas are densely populated which makes them vulnerable to flood impacts. These areas are vulnerable to floods because of three important reasons: exposure, susceptibility and resilience. That means the vulnerability of each area is reflective of the exposure, susceptibility and the ability of that area to adapt and recover from the effects of those conditions (Meulen, 2012). Exposure is the scope that human Settlements and people's live are positioned in flood risk area (UNDP/BCPR, 2004). Susceptibility is exposed factors in the system, which affects the probabilities of being

harmed during floods (UNESCO-IHE, 2013). Resilience is adaptation capacity of each community to changes in hazardous area by modifying itself to achieve an acceptable structural and functional level (Galderisi, 2005). With these indicators, additional information can be provided for vulnerability reduction.

The interaction between vulnerability factors and the vulnerability components in different spatial scales include river basin, sub catchment and urban area serve as the base of this methodology (Balica, 2007). Although there are some other grouping for component and indicators of this system. For instance, (Dapeng *et.al.* 2012) suggests multidimensional vulnerability with four components including population vulnerability, death vulnerability, Agriculture and economic vulnerability. But with regard to urban scale, FVI system as mentioned by (Balica, 2012) is more relevant for urban areas. The general formula for FVI is calculated by classifying the component in the three groups of indicators: exposure (E), susceptibility (S) and resilience (R) (Balica *et.al.*, 2012).

2.6 Review of Related Literature

2.6.1 Landuse Landcover Change

Belaid (2003) conducted a research on urban rural land use change detection on agricultural land using remote sensing and GIS technologies in Morocco and Saudi Arabia. The study made use of landsat TM and Spot Hev. The changes that occured in the last 20years in Morocco and 16years in Saudi Arabia were estimated. The overall findings indicated that urbanization has impacted mainly on agricultural lands.

Screenivasulu and Bhaskar (2010) carried out a study on change detection in landuse and land cover in Devak basin, Jammu and Kashmir India. Land use and land cover maps of 1958, 1979, 1990 and 1998 were used for detection of changes in Agricultural lands open scurb and scattered trees was reduced from 46.17% in 1958 to 9.90% in 1998. Agriculture with sparse habitation increased from 7.09% to 13.92 over other study period.

Balogun et al. (2011) conducted a research on the analysis of urban expansion and landuse change in Akure using remote sensing and GIS techniques. The study area was classified into arable land, bare surface, built up area, dense forest and water bodies. The percentage of the change within the study period shows 11.24, -5.86, 28.36, 33.81 and 0.13 respectively. The projection to 2020 may likely follow the same trend as observed between 1986 – 2007.

Ismail et al. (2010) did a study on the spatial growth of urban Kazaure in Jigawa State. The study made use of landsat TM of 1988 and Landsat ETM imageries of 1999 and 2007. Through the use of post classification change detection in GIS and structured questionnaires administered randomly, both stratified and systematic. It was revealed that the study area expanded from 12.2% in 1988 to 13.5% in 1999 and 29.7% in 2007. The bare surface has also decreased from 34.2% in 1988 to 13.4% in 1999 and finally to 4.1% in 2007. This implies a rapid phase of urbanization.

Mishar et al (2012) the project examined the use of remote sensing and GIS in mapping urban sprawl in Bhubaneswar from 1930 to 2005. The research detected changes of built up areas and population between 1930, 2005 and 2031. The findings indicated that the trend of change between 1930 and 2005 is similar to that of 2031.

Mashee and Malthus (2013) conducted a study on monitoring of urban expansion in the city of Riyadh, Saudi Arabia. The research made use of remote sensing technology (objected oriented image analysis) to monitor urban growth between 1994 and 2007. Two multispectral spot image were used and thee findings revealed that urban expansion extended to approximately 193.88km^2 during 14years.

Fichera et al (2012) carried out a research on land cover classification and change detection using multi-temporal remote sensed imagery and landscape matrics from 1954 to 2004. Avellino southern Italy aerial photo (1954) and landsat (MSS 1975, TM 1985 and 1993, ETM+ 2004 were used to characterized the dynamic of change during the fifty years period. The result revealed that the patterns of change are linked to both natural and social processes.

Ndabula et al (2013) analysed theSpatio-temporal changes in land use land cover structure in Kaduna. The study made use of five quantitative indices: vegetation index (NDVI), land us land cover (LULC) change intensity index (Ti), Dynamic index (KT) integrated index (Ld) and rate of change (Ai). These indices critically analysed the extent, rate as well as magnitude of change among various LULC in the study area. The result showed a decreasing vegetation cover and increasing bare surfaces with Ti, 5.75% built up 4.08% and the highest contribution rates (Ai) of 49 and 35 % respectively. Built up has the highest dynamic index (Ki) 2.29%.

Abbas and Arigbede (2011) carried out a research on sustainable management in Zaria using remote sensing and GIS. The study looked at land use land cover changes between 1985 and 2005 using landsat, spot and digital globe imageries. The result showed that the built up areas increased from 2.3% in 1985 to 36.4% in 2005, water bodies

decreased from 22.5% to 6.5% and cultivated areas decreases from 44% to 40% in 1985 to 2005.

Ejao and Abdullahi (2013) conducted a study on the Spatio temporal changes in land use land cover in Suleja between 1987 and 2012. The study used ILWIS 3.3 software for classification of 1987, 2001 and 2012 satellite images. The result shows an increase in area covered by built up land,farm land and bare soil, while there was a decline in vegetation cover.

Isham (2014) assessed risk of urban flash flood using inundation model in Terre Haute Indiana USA. The results revealed that an increase in developed areas led to an increase in very high flash flood risk in the study area. The model determines location of flash flooding but spatial extent flooding is not reliable based on field validation.

The aforementioned landuse and landcover analysis have used several GIS techniques and other conventional methods to study the LULC dynamics of their various study areas. But the method explored in this research deals with a set of probabilities that can accurately quantified and predict the level of landuse and landcover change overtime which the previous studies have fallen short of.

2.6.2 Hydrological Modelling

Bhatt (2012) looked at the new generation of high resolution accessible national geospatial data serving as a practical basis for numerical watershed simulations in the state Pennsylvania. The study used a tightly coupled interface to efficiently and accurately prototype, execute and analyse distribution model simulation of the watershed. A coupled flow transport age model was developed to simulate the transport

of the environmental isotopic traces, estimate the spatial distribution of age multi-state system and seasonality of the watershed residence time.

Smith (2012) conducted a study on the conceptual hydrological modelling insights in to model development and prediction in Unguaged basins. The study developed methods for improved statistical implementation of hydrologic models through development of a local likelihood functions across catchment conditions and the introduction of time domain transformation that was not previously used in hydrological modelling. The study also introduced a new hierarchical bayensian approach that was shown to accurately quantify uncertainty at an ungauged catchment based on pooled information from similar gauged catchment.

Johnson (1997) applied a continuous hydrological model that uses the SCS method (QUALHYMO) on the Annapolis river watershed to attempt to determine the applicability of QUALHYMO and SCS method to large watersheds. The study revealed a favourable result with simulated flow results typically close to actual recorded values of flow. Based on the findings the model is good for use on large and small watersheds.

Cao (2012) developed and tested a GIS based hydrologic data management, analysis and modelling software system in Idaho. The study used the consortium of university for the advancement of Hydrologic Science (CUAHSI), Hydrologic Information System (HIS), HydroDesktop, USGS National Water Information System (NWIS) and EPA. STORage and ReTrival (STORET) systems. The results show that the use of HydroDesktop is 27% to 72% more efficient than the other methods tested.

Bandaragoda (2008) carried out a study on the distributed hydrological modelling for stream flow prediction at Unguaged basins. The study used spatially distributed hydrologic models with spatially distributed precipitation inputs, advanced multi-objective calibration techniques that estimate parameter uncertainty and use stream guage and temperature data from multiple locations and the relationship between high resolution soil data and stream flow recession for use in prior parameter estimation in Unguage catchments. The research contributed to the broad quest to reduce uncertainty in predictions at Unguaged basin.

Aderogba (2012) conducted qualitative study on sustainable growth and development of cities and towns in Nigeria affected by the 2012 floods. Data on floods, drainage channels, run-off, effects of human activities on floods and interviews were conducted with professionals and urban dwellers. Findings revealed that human factors are predominantly the cause of flooding in the cities.

Yahaya et al. (2010) carried out a study in the Hadejia-Jama'are River Basin in Kano. The research used a combination of PCM (Pairwise Comparison Method) and ranking methods to calculate the contribution of annual rainfall, basin slope, drainage network, land cover and soil type to flood vulnerability within the basin. Rainfall, drainage network and basin slope were found to be the highest contributors to flood risk within the basin. The results were linked into the raster based GIS data and vulnerability maps were created.

2.6.3 Flood Vulnerability and Risk

Nabegu (2014) assessed the vulnerability of household to flooding in Kano state, using questionnaire survey, infrastructure analysis and flood impact information of 2012 flood disaster in Kano. The study covered households in areas that had experienced heavy, medium and light damage; it also explored household characteristics before and after the flood disaster, different coping mechanisms and analysis of infrastructure. The result indicates spatial variations between the zones in coping strength and vulnerability.

Nwilo, Olayinka, Adzandeh (2012) using GIS and Cellular Frame Approach did a flood modeling and vulnerability assessment of settlements in the Adamawa State flood plains. They adopted remote sensing and Cellular Automation Evolutionary Slope and River (CAESAR) to determine inundation level and assess vulnerability of settlements. The study shows that 134 settlements are at risk during the low, medium and high flow regimes.

Fosu, Forkuo and Asare (2012) conducted a study to map out hazard prone areas of the Susan River, Kumasi, Ghana. The study used HEC-RAS as the hydraulic model and geometric data was extracted from DEM, topographic maps and field measurements. The data was classified into various land cover types. The study produced a hazard map which clearly show the spatial distribution of flooded areas usually located in areas with relatively low relief. HEC-RAS is a hydraulic model that needs input from hydrologic model such as HEC-HMS for better and accurate results but the HEC-HMS model has a routing method embedded within the model which makes it a more robust model.

Alghmand et al. (2010) conducted a study on river flood hazard mapping of Kayu Ara River basin, Malasiya. HEC-HMS and HEC-RAS were used as hydrological and hydraulic models respectively. The generated river flood hazard was based on water

depth and flow velocity maps prepared according to hydraulic results. The results showed that rainfall magnitude and drainage basin land use development condition have significant influence on river flood hazard maps pattern although rainfall had a higher influence than the land use development conditions in the drainage basin. This study only considered the end point of the runoff which is the outlet and the relieving river the catchment area further more the implication of the outcome of the flood events to the inhabitant which this study incorporate.

Samarasinghea etal. (2010) conducted a study in Kalu Ganga River, Sri Lanka to validate flood inundation models using satellite data. In the study, flood extent was extracted from satellite images available for one in 50 years flood events that occurred in June 2008 in Kalu Ganga River, Sri Lanka and was compared with the flood extent derived from the flood extent of the 50 year rainfall using HEC-HMS and HEC-RAS. The study was carried out to develop, demonstrate and validate an information system for flood forecasting, planning and management using remotely sensed data with the help of flood hazard maps for different return periods (10, 20, 50, and 100 years). The research revealed that flood extent maps derived from the models satisfactorily matches that of the satellite image.

Ojigi, Abdulkadir and Aderoju (2013) carried out a Geo-spatial mapping and analysis of the 2012 flood disaster in central parts of Nigeria as a tool for contingency planning and emergency management. The study used satellite Imageries (MODIS Provided by NASA, Niger Sat-1 2007 and Quikbird 2006) base maps, SRTM DEM and flood photographs. It revealed that a comparison of the prior and during images of the flooded areas showed that in 2012 both Rivers Niger and Benue burst their banks, engulfing the

flood plains which lead to displacement of 566 thousand people,crops ravaged and transport routes severed.

Olajuyigbe, Rotowa and Durojaye (2012) conducted a qualitative assessment of flood hazard in MILE 12, Lagos using house heads and Lagos State physical Development Authority (LASPPDA) officials as respondents. The study revealed that the perennial flooding was as a result of consistent high rainfall, water released from Oyan Dam of Ogun state, blockage of drainages, narrow river channels and construction along flood plains.

Ishaya, Ifatimehin and Abaje (2009) mapped flood vulnerable areas in Gwagwalada urban area in Nigeria. The study used topographic map and Landsat Tm image of 1991 and 2001 respectively. ILWIS was used to generate classified landuse/ Landcover map, Digital Terrain Map and flood vulnerability map of the study area. The result revealed that areas lying along the banks of River Usuma and the old town were most vulnerable to floods due to incessant violation of land use plan, old nature of structures, population growth and poor nature of building materials.

Ogba, Okon and Idoko (2010) carried out a research on flood management in Calabar using GIS. The study looked at the challenges of climate change, rapid land use changes and the fragile geomorphic state of the city to determine the spatial flooding situation and degree of susceptibility. The identified flooding indicators were represented as thematic layers and subsequently simulated to generate flooding susceptibility map. The results revealed that the poorly planned part of the city and flood plain were most liable to flood and this constituted over 50% of the total area.

Cummings, Todhunter and Rundquist (2010) evaluated community relocation as a flood mitigation response to terminal lake flooding in Minnewaukan North Dakota using Hazus MH flood model. The model was used to examine potential flood damages in Minnewaukan associated with potential future lake levels. The study used structure elevation, the 2010 real property assessment book for the city and more than 200 individual property cards. The findings showed value of inundated buildings and flood damage profiles which indicate the functionality of Hazus MH can be extended to examining lakeshore flood hazard and an important geo-visualization tool in evaluating relocation as a flood mitigation alternative.

Garcia-Pintado, Neal, Mason, Dance and Bates (2013) carried out a research on flood modeling using Scheduled Satellite based Synthetic Apature Radar (SAR) acquisition for sequential assimilation. Satellite – based SAR was intersected with Digital elevation Model of the flood plain which provides water level observations which was assimilated in to a hydrodynamic model, using an Ensemble Transform Kalman Filter (ETKF) and a synthetic analysis with the 2D hydrodynamic model LISFLOOD-FP. The result revealed a clear improvement in keeping flood forecast on track and the imagery obtained have a large influence on forecast statistics.

Deitz (2014) conducted a research on distributed hydrologic modelling of large storm events in the Houston Galveston region. The study used the probable maximum precipitation (PMP) and precipitation depth duration frequency (PDDF) to design and predict the shape, pattern, size and intensity of large rainfall events. The study also used the Hydro meteorological Reports (HMR) 52 as well as local hydrologic reports. A 24 hours PMP storm event was created for the upper Gulf of Mexico. The result indicated

that there is a double peak phenomenon with flows from the west draining earlier than flows from the north. This gave an insight to relative timing of upland runoff and hurricane surge.

Robinson (2010) analysed flood prediction using distributed hydrologic modelling in the Yuna River Basin of Dominican Republic. As a result of the deadly flash floods in its mountainous upper researches, the model was adopted to understand the behaviour of an act as a resource for flood control decisions since guage and hydrologic data in the basin is sparse, the model customized and calibrated historic storms. The outcome reveals that multiple structure approach and a non structural approach is necessary to abate flash floods.

Whiteaker (2005) developed a geographically integrated hydrologic system. The study used HECHMS as the hydrologic simulation model, Archydro as the Hydrologic data model and NEXRAD as the workflow model. It was revealed that the schematic processor gives the user the ability to simulate hydrologic behaviour at the feature level. The schematic processor may be valuable tool when feature computations are required.

Presky (2015) conducted a hydrologic and hydraulic analysis of the New York City green storm water infrastructure. The green street are a type of source control that utilize bio-retention and reduce storm water runoff. Three models were developed; model I account for hydraulic and interception, model II was a SWMM model that did not account for hydraulic and interceptions and model III behaves the same way that SWMM model does except that it accounts for hydraulic. The study revealed about 32% capture of the gross precipitation. The large difference exists because interception

captures a small percentage of large storms, which account for a large portion of the gross precipitation and a large percentage of frequent small storms.

Tha (2004) used the Soil and Water Assessment Tool (SWAT) model to study the upper Mississippi River Basin (UMRB). The study conducted a sensitivity analysis using influence coefficient method for eight (8) selected hydrologic input parameters to identify the most to the least sensitive parameters. A further detailed sensitivity analysis was performed for the three most sensitive parameters, Curve Number (CN), Evaporation Compensation Factor (ESCO) and Soil Available Water Capacity (SOL-AWC). The impacts of eight climate change scenarios including a simplified replication of a previously reported future climate projections were then analysed relative to the baseline scenarios. The results indicate that UMRB hydrology is very sensitive to potential future climate changes, resulting in increased periods of flooding or drought.

Warms (2014) carried out a hydrologic modelling of a small ungauged basin in the Sahel. The study selected three criterion; difficulty in calibrating hydrologic models in ungauged basins, sharing of the unique calibration procedure and test the hypothesis using the calibrated hydrologic model. The results revealed extreme difficulty and inaccuracy in the result.

Wei (2004) explored the potential of integrating GIS and computerized hydrologic modelling in storm water runoff and streamflow simulation in watershed planning. Two hydrologic models HEC-HMS and HEC, GeoHMS were used to estimate the current condition of storm water runoff and streamflow in Wei mill creek basin, Hamilton Country, Ohio. The study further investigated the impact of urbanization on the hydrologic health functioning of the basin based on different land use scenarios. It was

revealed that a change in infiltration by impervious layers increased runoff and reduced time to peak discharge.

Kang (2011) used a prototype GIS based tightly coupled object oriented framework called GIS and Hydrologic Information System modelling object (GHISMO) and the storage release based distributed hydrologic model (STORE DHM) to test its flexibility to adopt additional modules and simulated multiple hydrologic events in three basins in Indiana. The STORE DHM model was able to predict runoff hydrographs for different types of events in terms of storm duration, peak flow magnitude and time to peak. In addition, STORE DHM, output was compared with output of spatially distribute direct hydrograph travel time method (SDDH). The results indicated better performance of the STORE DHM and GHISMO.

Generally the reviewed studies have made attempt to analyse issues on LULC, runoff generation, vulnerability and risk. Most have used models or methods that are equally good but with some deficiencies which were identified and remedied by the models and method used in this study for example the issue of generating and calibrating runoff of an ungauged basin which the HEC-HMS has the ability to overcome, the FVI which is easier method yieldaccurate results through interaction of major component of vulnerability. This particular study has looked at the issue of flood management in a more holistic way by using LULC, runoff generation, vulnerability and risk through various sought out methods and models which non of the aforementioned studies did.

CHAPTER THREE

STUDY AREA AND METHODOLOGY

3.1 The Study Area

3.1.1 Location

Kano Metropolis is located within latitudes $11^0$52'30"N to $12^0$7'30"N and Longitudes $8^0$25'30"E to $8^0$40'E. The boundary of the Metropolis keeps changing with time (Mortimore, 1989). The Metropolis is made up of eight Local Government Areas namely: Municipal, Gwale, Dala, Fagge, Tarauni, Nassarawa, Kumbotso, and Ungoggo (Fig. 3.1). The study area comprises of two drainage basins: the Challawa river basin occupies the southern part of the metropolis with an area of 109.8km^2, seventeen sub-basins and eight junctions while the Jakara river basins is situated in the northern part of

the metropolis with an area of 104.9km^2, fifteen sub-basins and seven junctions (Fig. 3.2).

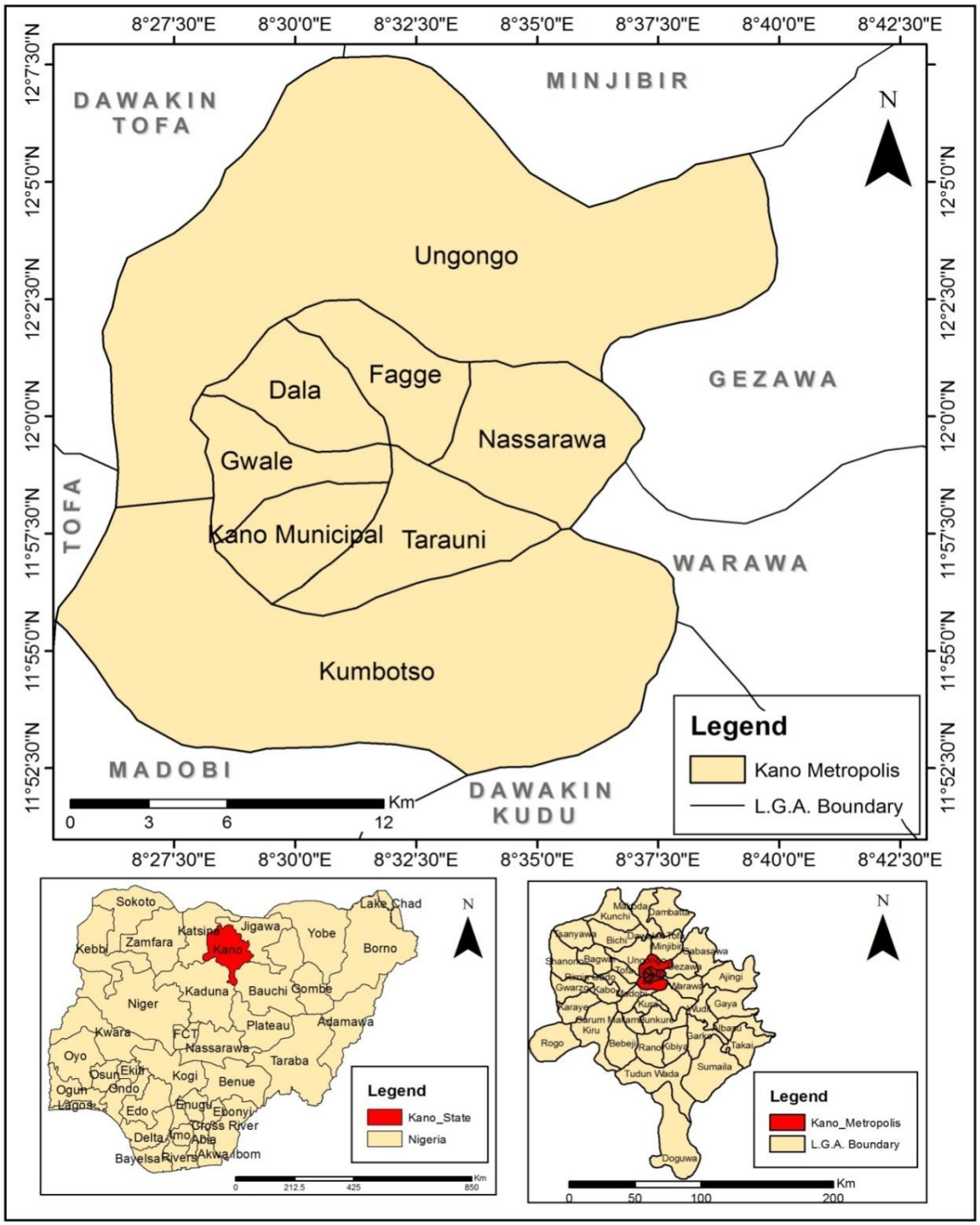


Figure 3.1: Map of the Study Area
Source:Adapted from the Administrative map of Kano State.

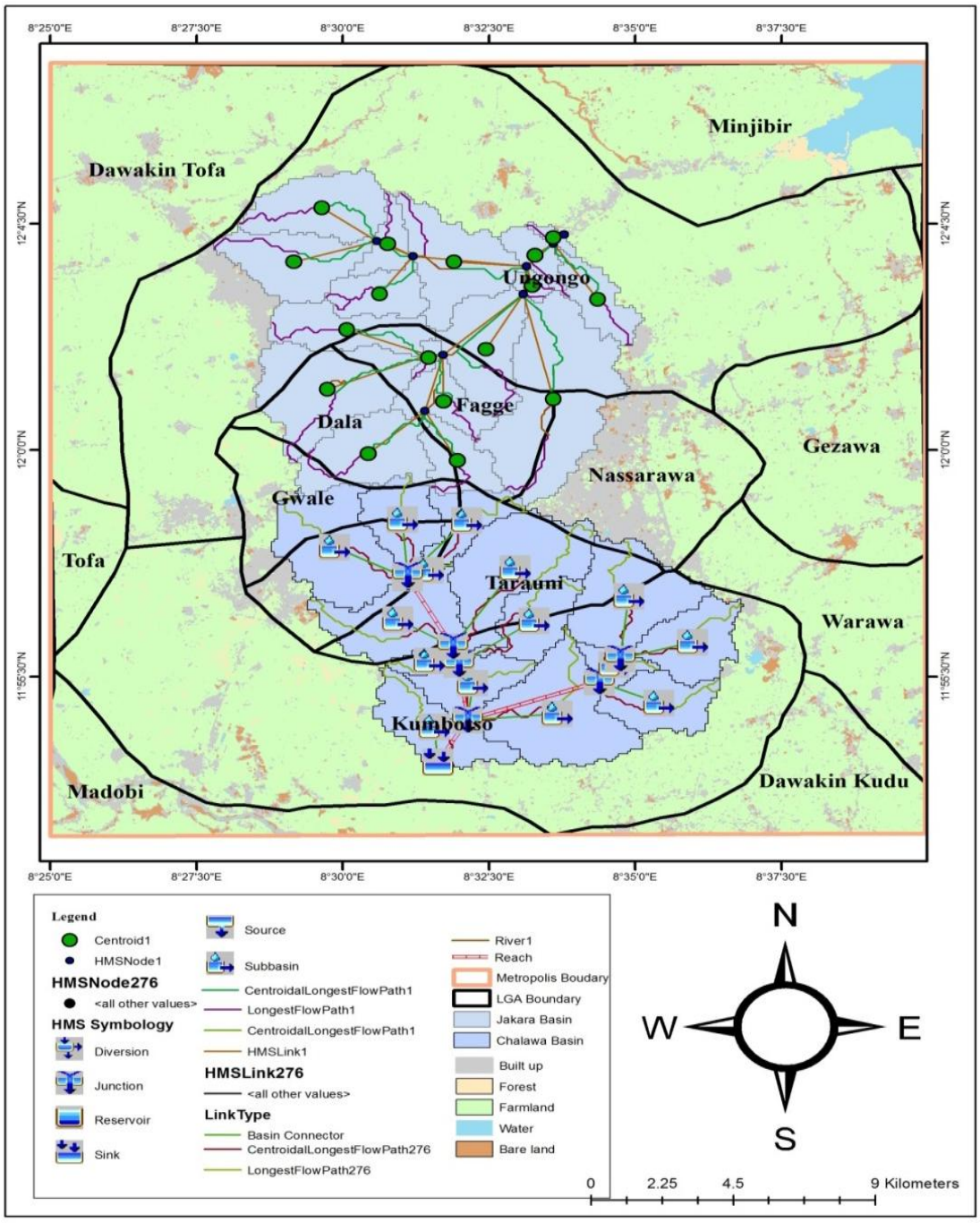


Figure 3.2: Map of Kano Metropolis Showing Drainage System
Source: Modified Kano State Topographic Map (Ministry of Land and Survey)

3.1.2 Weather and Climate

The Kano Region is characterised with marked wet and dry seasons. Generally, the Region has a semi-arid climate, with a mean daily temperature of 30^0C. The months of December to February are colder, with the lowest temperature recorded around 20^0C. The rainfall regime is characterized by two seasons, namely, the rainy season from May to October and the dry season from November to April. The average annual rainfall is about 884mm increasing from north to south. In the extreme south, it could reach 1200mm per annum around Riruwai and Doguwa.

The climate is the tropical wet and dry type coded as Aw based on the Koppen's classification of climate. Temperature is a very critical element in this area. Temperature in the Region ranges from 21^oC in the coldest months (December/January) to 40^oC in the hottest months (April/March). Four distinct seasons are experienced, which are the dry and cool, dry and hot, wet and warm, and dry and warm seasons (Olofin, 1987).

The seasons are determined by the movement of two air masses: a moist cool southerly air mass known as south-westerlies and a hot and dry northern air mass called the north-easterlies. The moist southern air forms a wedge under the lighter dry air and the region where the two air masses meet is primarily an area of pronounced moisture gradient. The humidity gradient is called the intertropical discontinuity (ITD).

The annual motion of the ITD is northwards between February and August and southwards between September and January. The north-south movement of the ITD influences weather pattern. Maximum rainfall is recorded in an area of considerable

disturbance (air movement) 8^{o} to 9^{o} southwards of the ITD. However, when disturbance is limited or when the northward movement of the ITD is restricted, drought is recorded. The level of disturbance and the northward movement of the ITD are influenced by the global pattern of pressure and winds as well as the interaction of the surface air and the upper air mass (the jetstreams). When the ITD is southwards, the Region is under the influence of the north easterlies. The weather changes arising from the movement of the ITD gives the four seasons (MARDITECH, 2011).

3.1.2.1Hot and Dry Season

The ITD starts its southward movement in February and between March and May it has no considerable influence in the Region and the weather is hot and dry during the rani season. The mean temperature is 28^{o}C to 30^{o}C while this is the season when the "false" start of the rain is recorded in May. A few rainfall instances are recorded in May and rainy days are separated by days of dry spell and less than 1% of the annual rainfall is recorded in May.

3.1.2.2 Cool and dry season

The ITD reaches its southern limit during this season and the Region is under the influence of the northeasterly winds which brings a cool and dusty weather called 'Harmattan". From December to February, the dry air from the north brings no rainfall. This is the cool season when temperature is 25^{o} to 27^{o}C.

3.1.2.3 Warm and dry season

The ITD is now in its southward retreat and only a few showers may be recorded in October accounting for less than 8% of the annual rainfall. This is the season between October and November when flooding rarely occurs. Average temperature is 28^{o}-29^{o}C and evaporation is in excess of rainfall. This is a season when soil moisture is depleted and stream flow recedes.

3.1.2.4Warm and Wet Season

The ITD has by now made considerable advance northward and rainfall is recorded in the Region. Heavy rains are recorded mainly in the evenings for some hours, with high intensity in the first forty minutes of the rainfall occurrence. Over 90% of the annual rainfall in the Region is recorded in this season. This is the humid period when surface runoff is available for stream flow andtemperature drops to an average of 24^{o}C to 29^{o}C while evaporation is lower because of the higher relative humidity of the moist south westerlies air. This is why the runoff-coefficient is highest during this season and also flooding.

In terms of rainfall distribution, the Kano Region is divided into three zones (MARDITECH, 2011). The northernmost is “rainfall zone 1” with 110 to 130 rainy days a year. The second is rainfall zone 2” which lies south of the first with 120 to 130 rainy days a year. The southernmost is “rainfall zone 3” that has 130 to 150 rainy days per year. The monthly data consistently show that the rainfall reaches a peak in July and August in the Kano region, suggesting that flooding is most active in these two months. June is probably a period when soils are continuously being wetted. With this wetting,

the soil becomes saturated thereby increasing runoff. The high concentration of rainstorms in two months, July and August implies more than 55 % of the annual rainfall occurs within the 62 days in these two months (MARDITECH, 2011).

If the annual rainfall is 1000mm, 60% falls in July and August, and half of the days are rainy, the average daily rainfall would be 600/31 mm = 19mm. However, there will most likely be rainstorms of various sizes in any one period, implying that some storms will be much larger than 19mm. According to a study by Haskoning (1981), the one-day total precipitation with a return period of 1 in 5 years is about 90mm for Kano. From daily rainfall recorded at the Bayero University Meteorological Station (1988-2016) indicates that the number of rainstorms per month is relatively low, implying that the average rainstorm is relatively large, hence a possibility of flooding.

3.1.3 Drainage Basins

The drainage system emerges from the foothills of the Jos Plateau. As it flows it first runs vertically towards the north, until it reaches the confluence with the Challawa River. Together they flow in the eastern direction. At the first entry point, the dense vegetation cover of the Falgore Game Reserve (at the southern part) protects the flow of the river yielding very low sediments. The Reserve therefore serves as a filter to the Tiga Reservoir. However, human intervention on the forest resources is making the reserve vulnerable. In addition to this, the Kano river is the main source of water for human consumption, particularly for urban Kano and the settlements along the course of the River, raising issues of flooding and water quality especially as it receives most of the effluents from the Sharada and Challawa Industrial Estates through the Salanta-Tatsawarki streams in the Metropolitan Kano (Yahaya et al. 2011).

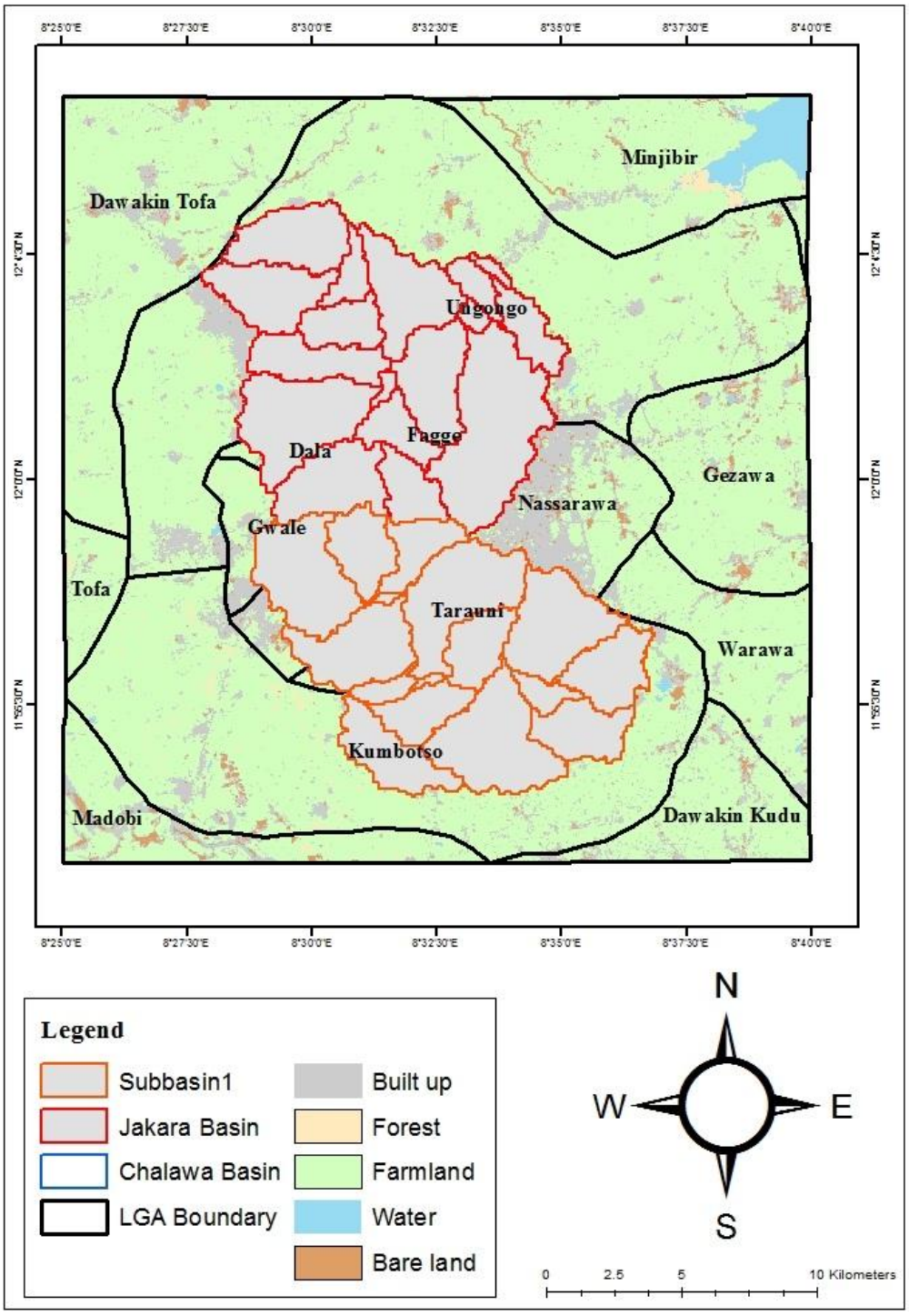


Figure 3.2: Kano Municipal Showing Drainage Basins
Source:Kano State Topographic Map (Ministry of Land and Survey)

3.1.3.1 The Jakara drainage basin

The first source of the river is traced into the Kano city (i.e. the Jakara/RafinMallam) and the second source is the Bompai Industrial Estate (i.e. the Getsi). The river and its tributaries have most of their length within the Metropolis. Along the stretch of the banks are rapid encroachment of settlements which increases their risk and vulnerability to flooding. For this, the quality of the water is very low and not suitable for many uses. The river was dammed at Wasai in Minjibir Local Government for the last three and a half decades without proper utilization. Before the dam, this flow disappeared into Yadai and Yukana sand dunes (in the north eastern part of the Region) and which still forms the only longitudinal dune fields in the present Kano State. Other rivers that joined the Jakara at Chedi in Minjibir Local Government are the Agalawa, Gwagwata and Fagwalawa Rivers from the north.

3.1.3.2 The Watari sub drainage basin

Watari River gets its sources from numerous tributaries west of Shanono and Gwarzo. The river passes through Bagwai where it was dammed. Downstream, the river flow through Janguza and joined the Challawa, settlements have sprung up within the system along flood plains. The Bagwai (i.e. Watari) Dam is one of the most productive dams in the Region that is utilised for variety of purposes, particularly dry season irrigation providing livelihoods to thousands of the rural populace.

3.1.3.3 The Chalawa drainage basin

In the western extreme of the Region, the Gari system takes its source from in the Katsina Highlands around Malumfashi, which also serves as one of the headwaters of

the Challawa River System which creates dendritic networks moving eastward. Some of its major tributaries include Koganya, Kwakwa, Jare and Marashi all of which join the Challawa River. The last three tributaries meet at Damagari in Tudun-Kaya, Karaye Local Government. Koganya flows into Challawa at the upstream of the Gorge Dam in Rogo Local Government area. Other Rivers from this axis that joined the Challawa are Kumanda, Kariya, Bagwari and Bargi. Also part of the system is the Salanta stream and the Kusalla River, which runs south through Kurugu where it was dammed. This is the source of water for Karaye and Gwarzo towns.

3.1.4 Geology

The geology of Kano is made up of the Basement Complex rocks (Uso, 1970) and (Olofin, 1987) which are deeply weathered, resulting in lateritic pans. Quarzite, undifferentiated meta-sediments and Basement Complex rocks of the Pre-cambrian and upper Cambrian origin make up more than two-third (2/3) of the Kano geological setting. Deep clay-rich regolith produced by prolonged weathering activities which subject them to laterization. Lateritic outcrops of the upland areas serve as caps for the regolith hills, for example GwauronDutse and Dalahillswhich aids run off. Other rock types include the well jointed Younger Granites of Jurassic origin (Olofin, 1991). The general height of the relief ranges from 500m in the lower plains to highlands of more than 1000m above sea level. The major landforms include the plains with grouped hills and alluvial channel complexes.

3.1.5 Soils

The soils of Kano are derived from the two main geological formations; the Basement Complex and the Chad Formation. The Basement Complex rocks are quite variable in size and composition and include granites and others. The soils on the Chad Formation, on the other hand, are poorly structured and excessively drained. They are derived mostly from the Aeolian parent materials.The soils are divided in to four main groups. Generally, the ferruginous tropical soils formed on crystalline acid rocks found in the south, south west and south east of the state. The brown and reddish brown soils and latosols occur in the northern part, the north eastern corner is occupied by the brown, reddish, juvenile and hydromorphic soils found along the alluvial channels. However, in view of the prolonged influence of the Sahara dusts in the area, all surface soils in the Kano contain Aeolian materials. The soils are generally free of stones. A common feature of soils in the Basement Complex area is the occurrence of plinthite or ferruginous hard pans which aids excessive runoff.

3.1.6 Vegetation

According to Olofin (1987), the Sudan Savanna can be said to be the typical vegetation of the Kano Region. It has scattered trees in open grassland with short grass species (under 1.2m tall) which co-dominates. The trees are usually characterized by broad canopies and they are seldom taller than 20 meters. The trees are well adapted to the environment. Water in form of rainfall is available for a few months in this region, as such majority of the species are deciduous and only few are evergreen (e.gTamarindusindica). Dorminant species found within the metropolis are *Vitex domiana, Isoberlina doka, Khaya senegalensis, Baanites aegyptica, Accacia lilotica,*

Azadirachta mdlca, Parkia biglobosa, Afzelia Africana, Fiscus thongigii, Tamarindus indica, Ceiba pentandra, Guira senegalensis and Vitallaria paradoxa etc.

3.1.7 Population

Population does not only represent the total number of human inhabitant in a particular area, but also its means of livelihoods, prospect, prosperity, and posterity. The phenomenal increase in human numbers in relation to the finite supply of basic life supporting resources, economic development and environmental quality makes the scenario a growing born of contention among both scholars and policy makers. This is because the population saga is bedeviled with both issues and challenges. Kano as a geographical entity can stand as one of the epicenters of rapid population growth with a dynamic population size, composition and distribution that evolved along the history and culture of the region.

An amazing issue is the population - land ratio, Kanowith a total land area of 45,792.5Km^2, had an average density of 53.3 persons per square kilometer in 1931 but by 2006, the density had increased by about 5.6 times (over 500%) with a density of about 300 persons/km^2.Another important characteristic of the population in the Kano area is the spatial distribution of people. The population is unevenly distributed with great variation between urban and rural areas and also between the northern and southern parts of the region. The highest numbers of people are concentrated within Kano Metropolis which comprises Municipal, Dala, Gwale, Nasarawa and Tarauni, Kumbotso and Ungoggo Local Government Areas. This has greatly influenced the rapid spread of natural land conversion into impervious lands.

3.2 METHODOLOGY

3.2.1 Reconnaissance survey

A reconnaissance survey was conducted to get acquainted with the study area in order to properly organize the method to be adopted for the study.

3.2.2 Types and sources of data

Table 3.1 presents types of data, sources of data and purpose

Table 3. 1: Data Type and Sources

	TYPES OF DATA	SOURCES	PURPOSE
1	Rainfall Data	AKIA,BUK,HJRBDA, NHA, IITA, NEXRAD,MARDITECH	To generate run-off
2	Soil data	BUK, soil science Dept, Ministry of environment	To aid in run-off and land cover analysis
3	Satellite imageries (Quick Bird 2012)	National Remote Sensing Centre, Jos.	To generate land-use/cover change, flood inundations
4	LandSat ETM+ (2001)	Glovis Website	For flood validation
5	Social, economic, physical and environmental data for2001 and 2012.	MDG Nigeria, NBS, NPC, WHO and KSBS.	For Vulnerability analysis
6	DEM (Digital Elevation Model)	Satellite imageries	drainage basin model development

3.2.3 Data Processing Method

FloodRisk analysis in Kano Metropolis included Hydrologic FVI and Land use/cover analysis.

3.2.3.1 Land use Classification

Supervised classification was applied, this was done to obtain land use and land cover map. The choice of this classification type was due to its accuracy level than unsupervised classification. However, supervised classification depends heavily on the training sites, the skill of the individual processing the image, and the spectral distinctness of the classes. If two or more classes are very similar to each other in terms of their spectral reflectance (e.g., annual-dominated grasslands vs. perennial grasslands), misclassifications will tend to be high. Supervised classification requires close attention to development of training data.A number of steps are required in order to accomplish this task as shown in Figure 3.2.

The first step was to download the satellite image, and then the image was georeferenced to the coordinate system of the study area from World Geodic System 1984 Projection to Universal Transverse Mercator (WGS84 to UTM, Zone 32N). Visual image by colour compositing of three band 3,2, and 1 for red, green and blue respectively.

The next step is to define spectral characteristics of different classes by identifying sample areas. Samples of a specific class include a number of training pixels into groups (classes) according to their spectral characteristics to see how it relates to the sample classes.

After defining the training sample, the method of maximum likelihood classification was applied in order to obtain the land use land cover classification.

3.2.3.3 Digital Elevation Model (DEM) Pre-processing

Digital Elevation Model defines the topography of the area by describing the elevation of any point at given location and specific spatial resolution as a digital file. It is one of essential spatial input for HEC-HMS to delineate watershed into a number of sub-watershed or sub-basins based on elevation. Drainage pattern, slope, channel width and stream length within the watershed was processed using the DEM. The raw DEM was downloaded from United States geographic Survey (USGS), Shuttle Radar Topography Mission (SRTM) with 90m resolution and projected using ArcGIS 10.3 software package.

DEM was used to access several potential catchments within the study area. The catchment for the study area was chosen for further investigation and processing. The extracted DEM for the catchment was further examined to visualize the drainage system and was compared with existing stream network on existing topo maps of the study area.

Figure 3.6shows the steps involved in terrain processing using HEC-Geo HMS and ArcHydro in ArcGIS software.

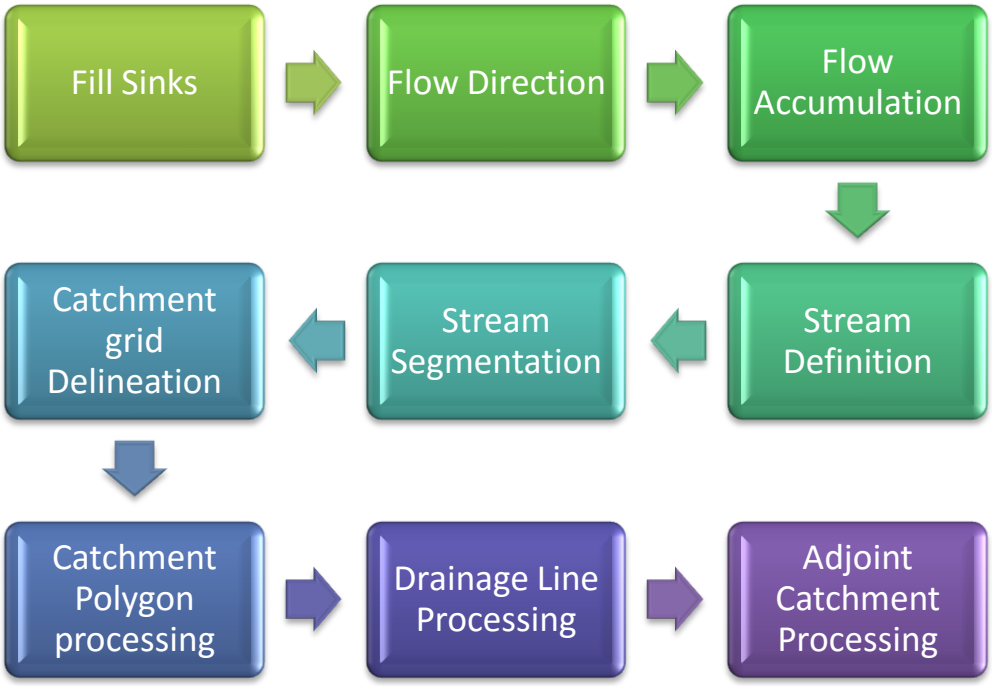


Figure 3.2: Physiographic Data Extraction Using HEC-Geo HMS and ArcHydro
Source: Fieldwork, 2016

The DEM was combined with topographic map sources to generate the agreed DEM using ArcHydro Extension tools. The DEM was then optimized through integrating of the existing digitized drainage to obtain a final DEM. The optimized DEM was processed through several steps using Arc hydro (Arc GIS extension) and HEC-Geo HMS such as fill sink, flow direction, flow accumulation, stream definition, stream segmentation, catchment grid delineation, catchment polygon processing, adjoining catchment processing, adjoining catchments, drainage point processing, longest flow path for catchment, watershed delineation, accumulation shapes and slope.

The DEM was then optimized for use in the model in ArcGIS, using HEC-GEOHMS extension. The processed DEM was further processed to create a HEC-HMS project which was then exported to HEC-HMS software for modeling. The processes involved the project setup, basin processing, basin characteristics, and finally HMS processing.

The HEC-GeoHMS project package has tools for defining the outlet for the watershed, and delineating the watershed for the HEC-HMS project. The HMS basin model was developed by using the same spatial data: the model is managed by defining two feature classes, the project point and project area. Management of model through project point and project area allow the user to see areas for which HMS basin model are already created, and also allow user to re-create models with different stream network threshold.

Finally, HMS project was set up, data management on the HEC-GeoHMS main view toolbar was selected. Figure 3.7 is a representation of the processes involved

3.2.3.4 Slope

Watershed slope reflects the rate of change of elevation with respect to distance along the principal flow path. After the principal flow path was delineated, and then the watershed slope was computed as the difference in elevation between the end points of principal flow path devided by hydrologic length of flow path using ArcGIS.

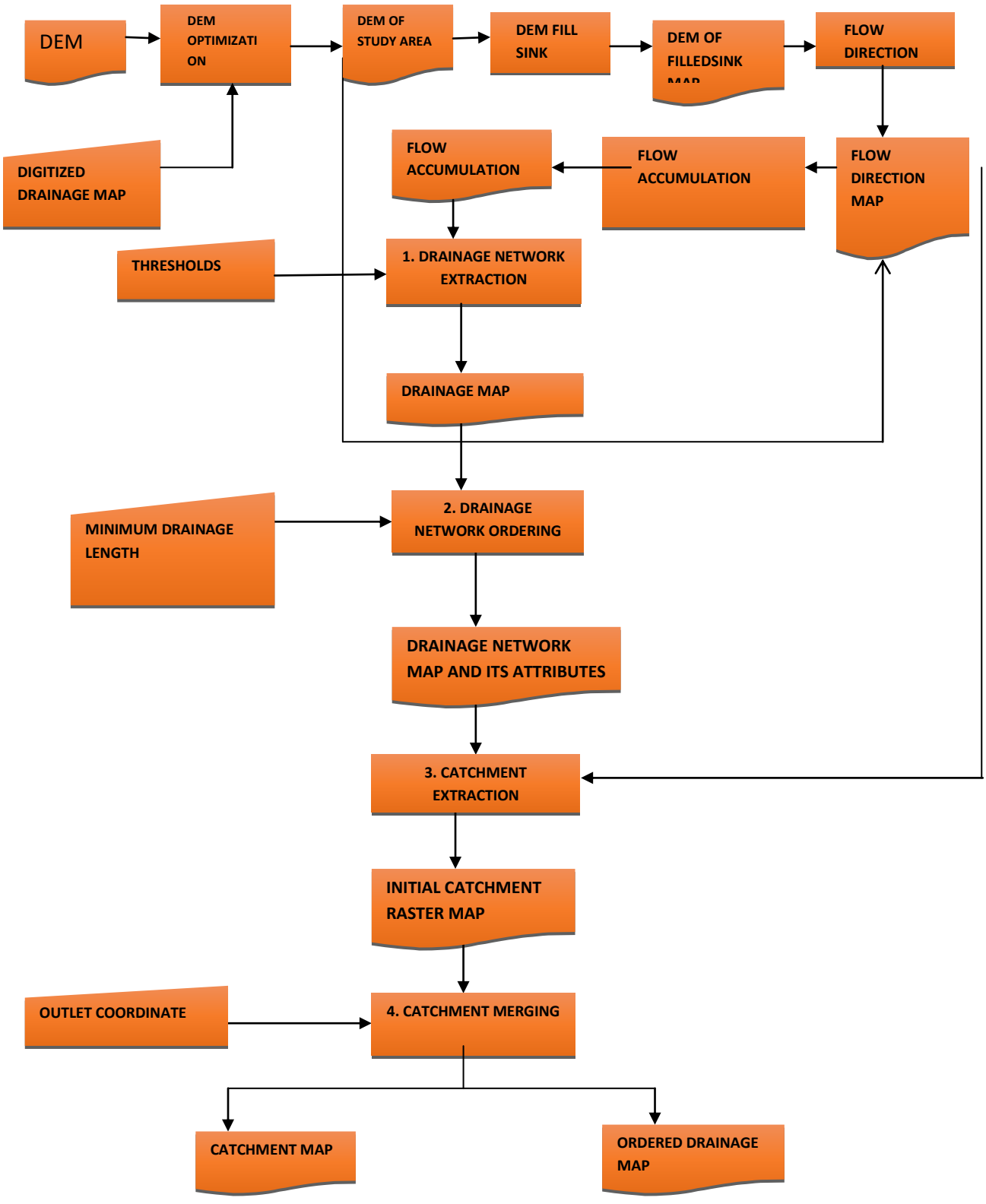


Figure 3. 7: HMS Processes
Source: Fieldwork, 2016

3.2.3.5 Soil Data

The soil data was accessed from Soil Science department Bayero University Kano and was projected to the desire coordinate system for further processing with the land use data in order to generate the catchment characteristics. The soil map was reclassified into four hydrological soil group (HSG) named A, B, C, and D based on their infiltration rate. The LULC map was also reclassified into four different categories and then, the land use, soil and slope maps were overlaid in order to generate the curve number grid (CN).

3.2.4 Data Analysis Method

Flood vulnerability and risk analysis in Kano municipal includes four main components; land use/cover analysis hydrological modeling, floods vulnerability and risk analysis.

Objective i: Conduct a Land-Use and Land-Cover Change Analyses of the Metropolis: This objective was achieved by broadly classifying each image set into impervious and pervious categories. After the classification, area coverage of each land-use/ land-cover change was determinedusing Markov chain analysis. The procedure includes:

i. Preliminary data processing of Landsat and Quick Bird images acquired in 2001, and 2012.
ii. Classification of multispectral imagery.
iii. Probability analysis to generate Transitional Probability Matrix andTransitional Area Matrix.
iv. Analysis using Markov chain method to generate land use change from 2001 to 2012 and to 2035.

Objective ii: determine the volume of run-off within the metropolis:

This was achieved through a Hydrological model (HEC HMS) which is regarded as an excellent tool for predicting drainage basin response to rainfall events and assessment of impacts of parameters such as land-use/ cover change on drainage basin hydrology. HEC-HMS4.1 was used as hydrological model linked to GIS anlysis using HEC-GeoHMS and Archydro extensions. In HEC-HMS model there are four main components for hydrological modeling; loss method, transform method, base-flowmethod and routing method. For each of these components a suitable method was chosen. In this study the following methods were selected because they suit the characteristics of the study area:SCS Loss Method**(**The SCS model in HEC-HMS 4.1.0 requires specification of the parameters as follows: initial loss, hydraulic conductivity, wetting front suction and volume moisture deficit. Initial loss, hydraulic conductivity and wetting front suction are functions of the drainage basin moisture at the beginning of the precipitation, texture class and pore size distribution, respectively.), SCS unit hydrograph**(**This method selects the lag, peak flow, and total time base as the critical parameter to define the Unit hydrograph),SCS Routingmethods was selected and applied for rainfall-runoff hydrographs in Kano Municipal.

Objective iii:Conduct a Flood Vulnerability Analysis of the Metropolis: To achieve this objective the Flood Vulnerability Index (FVI) developed by Balica *et.al*(2009) this method combines all the components of flood vulnerability in a simple less complicated equation and has a higher accuracy compared to Connor and Hiroki method was used: the overall FVI for each sub-basin was determined by calculating the index from the 27 indicators (see appendix II). These indicators have been linked with three factors of vulnerability: susceptibility, exposure and resilience. The general FVI equation (1) links

the values of all indicators to flood vulnerability components (social, economic, physical and environment).

$$FVI = \frac{Exposure \times Susceptibility}{Resilience}$$ .....Equation (1)

The indicators belonging to exposure and susceptibility increase the FVI and therefore placed at the numerator, however the indicators belonging to resilience decrease the FVIand this is why they are placed at the denominator (Dinh Kha*et.al*, 2011). The calculations of each component for each sub-basin are based on the following equation (Balica and Wright, 2010). See equation 2,3,4,5, a standardized method was used for adjusting indicator values to a scale of 0 to 1. The standardized equation of the FVI is as indicated in equation (6). Definition of terms in the equation (see Appendix III).

$SocialComponent$

$$FVI_S = \left\{\frac{P_D, P_{FA}, C_H, P_G, H_{DI}, C_M}{P_E, A/p, C_{PR}, S, W_S, E_R, E_S}\right\}$$ .....Equation (2)

$EconomicComponent$

$$FVI_{EC} = \left\{\frac{I_{ND}, C_R, U_M, U_G, R_T}{F_I, A_M I_{nv}}\right\}$$ .....Equation (3)

$EnvironmentalComponent$

$$FVI_{EN} = \left\{\frac{U_G, Rainfall}{E_v, L_u}\right\}$$ .....Equation (4)

$PhysicalComponent$

$$FVI_{PH} = \left\{\frac{T,}{E_v/Rainfall, S, L}\right\}$$ .....Equation (5)

$$FVI_{Standardize} = \left\{\frac{FVI_{Scale}}{FVI_{max}}\right\}$$ .....Equation (6)

$TotalFVI = \sum \mathrm{FVI_{S,}\ FVI_{EC,}\ FVI_{EN,}\ FVI_{PH}}$……Equation (7)

The flood vulnerability analysis was done using detailed evaluation of the four components of flood vulnerability: social, economic, environmental and physical. These components were gathered and calculated to give the overall flood vulnerability of the basins. The application of this formula equation (7) for each component lead to four district FVI indices:

$$\mathrm{FVI_{Social,}\ FVI_{economic,}\ FVI_{environmental}}\ \mathrm{and}\ \mathrm{FVI_{physical}}\ \ldots\ \ldots\ \ldots\ \ldots\ \ldots$$

Which aggregates into:

Total FVI= $\sum \mathrm{FVI_{S\ ,}\ FVI_{EC,}\ FVI_{EN,}\ FVI_{PH}}$.....Equation (7)

The outcome will be interpreted using the Balica*et.al*(2012) flood vulnerability designations, (see Appendix III).

Objective iv: To conduct a flood risk analysis of the metropolis

This objective was achieved by using the Sengtianthr (2007) approach. The results of the vulnerability level of the drainage sub- basins were combined with amount of run-off of individual sub-basins to give the flood risk level. (See Appendix I)

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Introduction

The results and discussions of this study are presented in line with the objectives of the study. This chapter is structured into the following sections: Section one is a presentation of land use and land cover changes over the study period, section two is a presentation of run-off amount at sub-basin and entire drainage basin level. Section three established the level of flood vulnerability of the drainage basins and the fourth section indicated the flood risk level of the study area.

4.2 Nature of Land Use and Land Cover Change in Kano Metropolis

This section presents the results and discussion of land use land cover change of the entire Kano metropolis. The study area was categorized into five (5) thematic classes under supervised classification which are; built-up areas, Forest, farmland, water and bare land. The analysis was carried out for 2001, 2012 and 2035. The Jakara Basin occupies the northern part of the metropolis comprising of 17 sub-basins within Gwale, Dala, Fagge, Ungoggo and Nassarawa while the Chalawa basins occupy the southern part of the metropolis comprising of 15 sub-basins within Kumbotso, Tarauni, Kano Municipal part of Gwale, Dala and Fagge, the entire study area covers an area of 767.23km^2.

4.2.1 Kano Metropolis 2001 Land Use and Land Cover

In 2001 over 60% of the metropolis was occupied by farmland and 19.7% by built-up areas. The sub-basins that made up most part of the built-up areas are W310, W280, W330 and W250 in Jakara basin and W170, W180, W210 and W200 in the Chalawa basin. This is believed to influence the peak discharge of the basins (see figure 4.1a, 4.1b and 4.1c), but as a result of the high percentage of open pervious surfaces, there is a possibility of high infiltration which results in low run- off. This depicts the findings of Balaid (2003) Ismail et.al. (2010), where it was observed that open spaces, forests, and farmlands increased the amount of infiltration or delayed time of peak discharge.

4.2.2 Kano metropolis 2012 land use Land Cover Change

The LULC in 2012 shows a different trend with the pervious surfaces (farmland, forest, bare land and water bodies) constituting less than 66% of the entire metropolis. The built-up areas increased from 150.9km^2 in 2001 to 263.4km^2 in 2012 almost a 50% increase. This signifies the increase in impervious surface and hence increased in runoff. These findings are in tune with the results of Ejao and Abdullahi (2013) and Mishra*et.al* (2012) where changes are skewed towards built-up areas as a result of rapid urban development. Figure 4.1a, 4.1b and4.1c indicates that sub-basins W160, W170, W180, W190 and W230 have had over 20% increase in built up areas in the Chalawa basin, while the Jakara basin had a 30% increase in built up areas in sub-basins W340, W330, W310, W280, and W270, which indicates a possible increase in run-off accumulation.

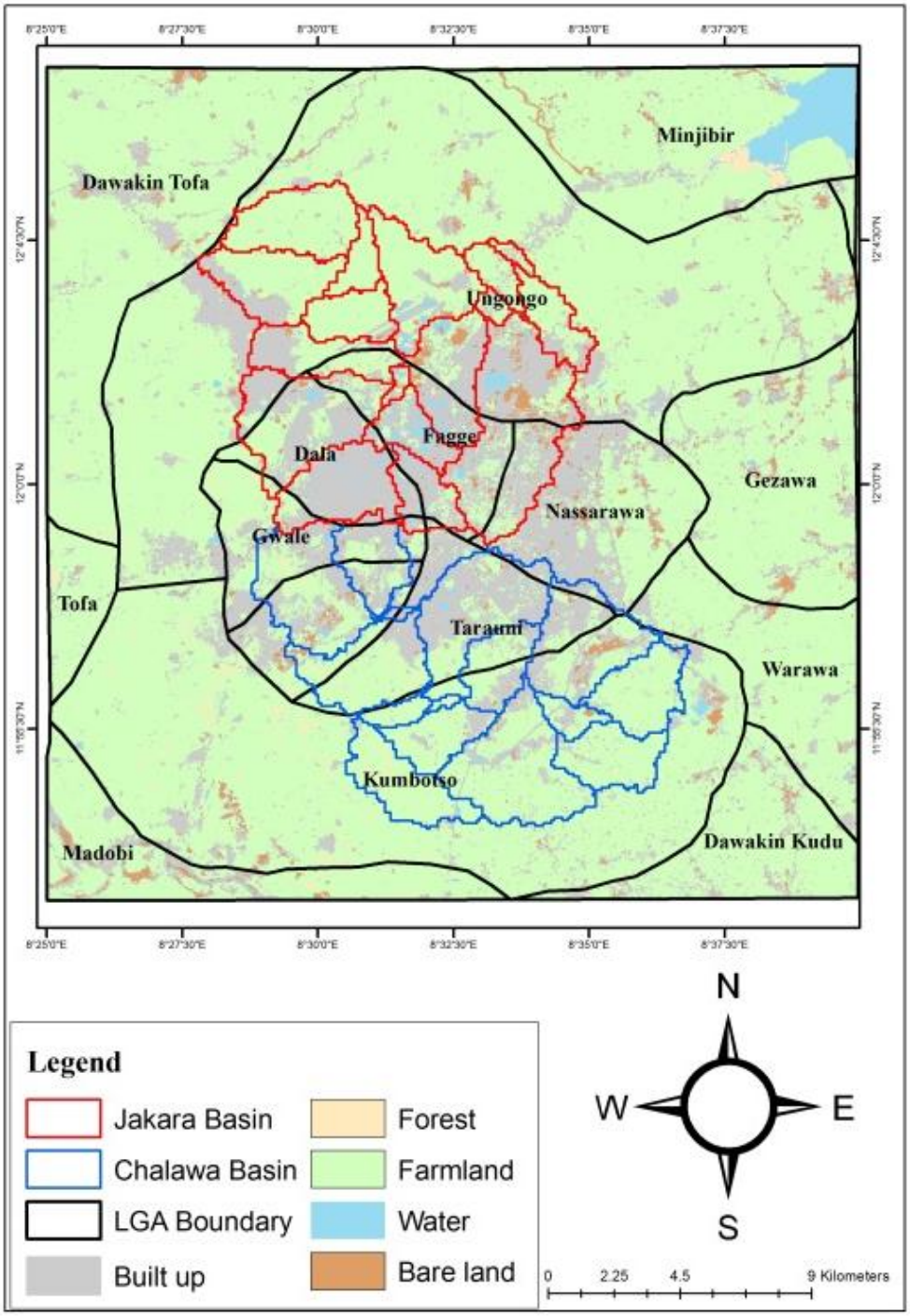


Figure 4.1a: Jakara and Chalawa Land Use Land Cover 2001
Source: Authors Analysis (2017)

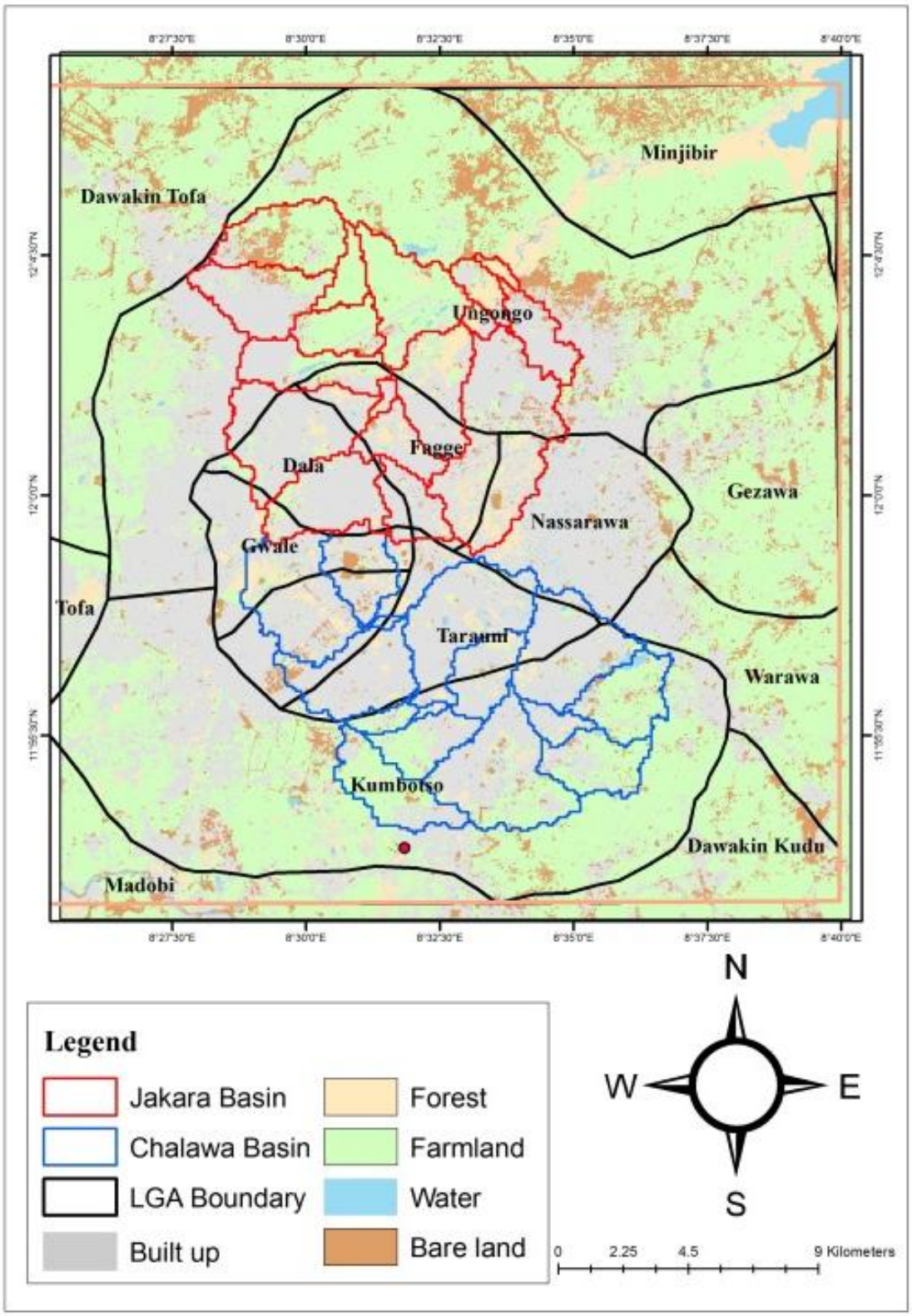


Figure 4.1b: Jakara and Chalawa Land Use Land Cover 2012
Source: Authors Analysis (2017)

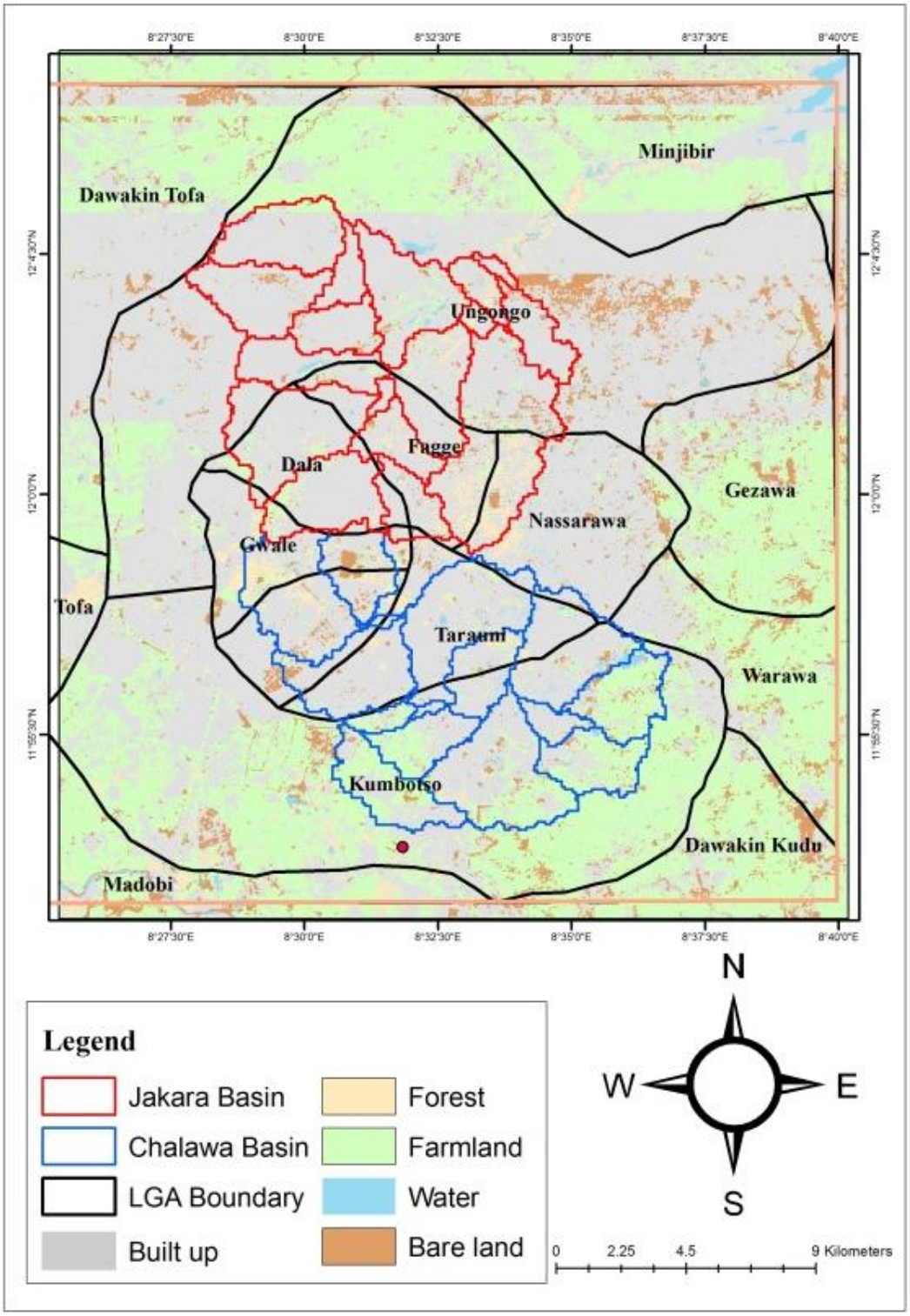


Figure 4.1c: Jakara and Chalawa Land Use Land Cover 2035
Source: Authors Analysis (2017)

4.2.3 Kano Metropolis 2035 Land use Land Cover Change Projection

The percentage of built-up areas in 2035 jumps to over 50% (Figure 4.1c, 4.1f and 4.1i) of the entire metropolis leaving the pervious surfaces with less than 45%. This sharp rise in impervious surfaces leads to increase in runoff. Balogun *et.al*(2011), Mashere and Malthus (2013) reported similar findings and attributed it to a rise in flash flood incidences in their study areas. Kano metropolis have experienced a drastic change in land use and land cover mostly from pervious to impervious surfaces which could be attributed to the rise in flood incidences as a result of run-off accumulation.Studies by Ishaya *et.al*(2009), Ogba *et.al*(2009) and Cummings *et.al*(2012) further reiterated the influence of rapid urbanization on flood occurrences

4.3 Run- Off Discharge of Jakara Drainage Basin

The Jakara basin has an area of 109.7km^2 and 17 sub-basins. The results presented below are simulations for rainfall events of 2001, 2012 and 2035 that resulted in massive flooding. The rainfall event of 2001 that occurred on the 25thof August had a total volume of 163mm^3 while that of 2012 had a volume of 143mm^3 on the 7th of August which was also replicated for 2035 forecast.

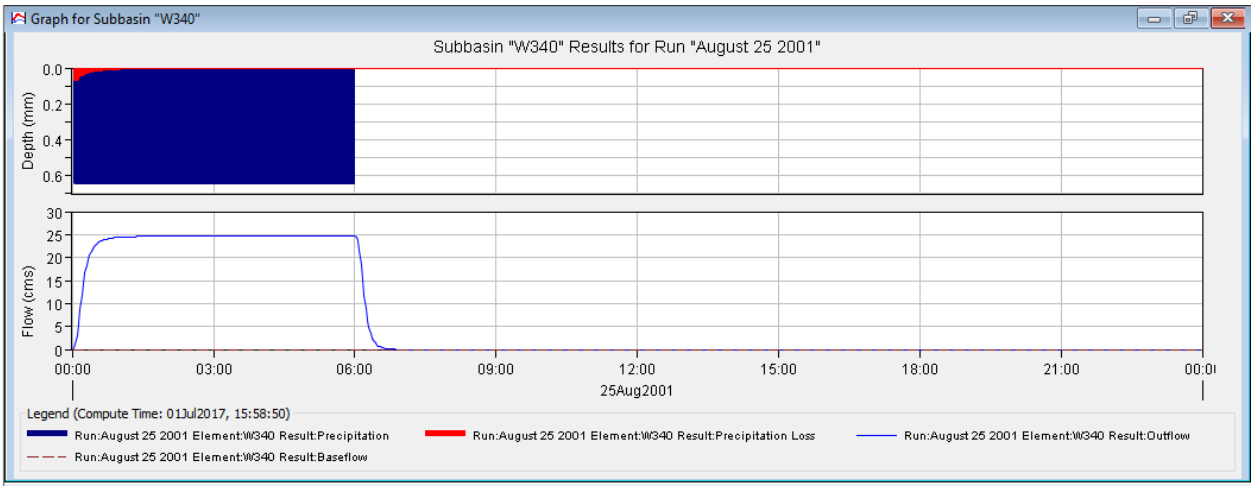


Figure 4.2 a: Run-off simulation of Sub- Basin W340
Source: Authors Analysis (2017)

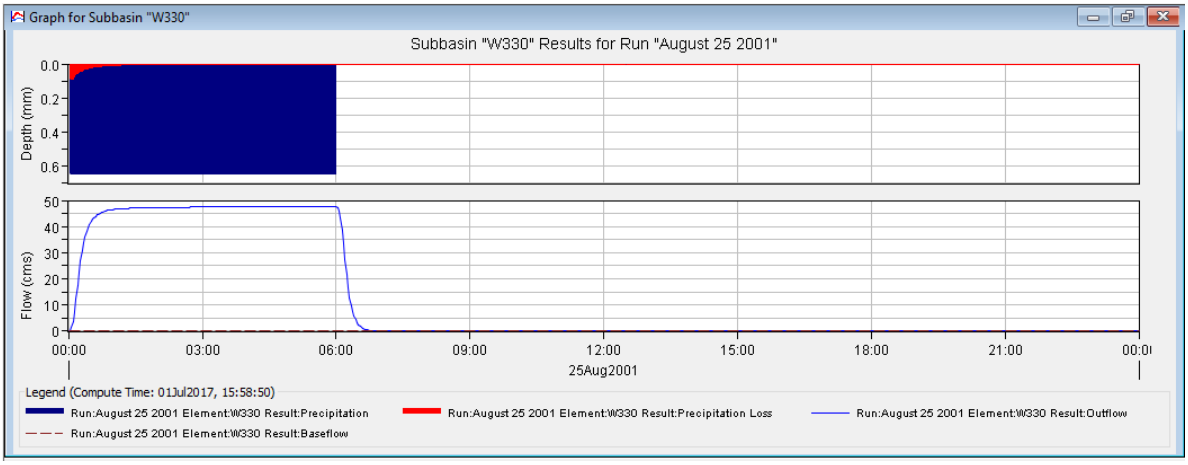


Figure 4.2 b: Sub Basin W330
Source: Authors Analysis (2017)

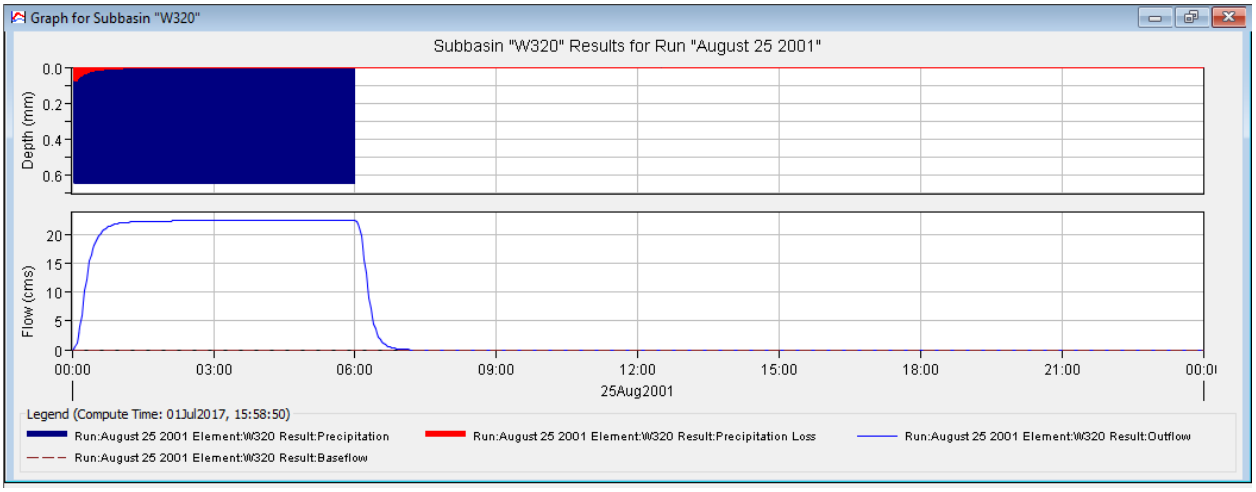


Figure 4.2 c: Sub Basin W320
Source: Authors Analysis (2017)

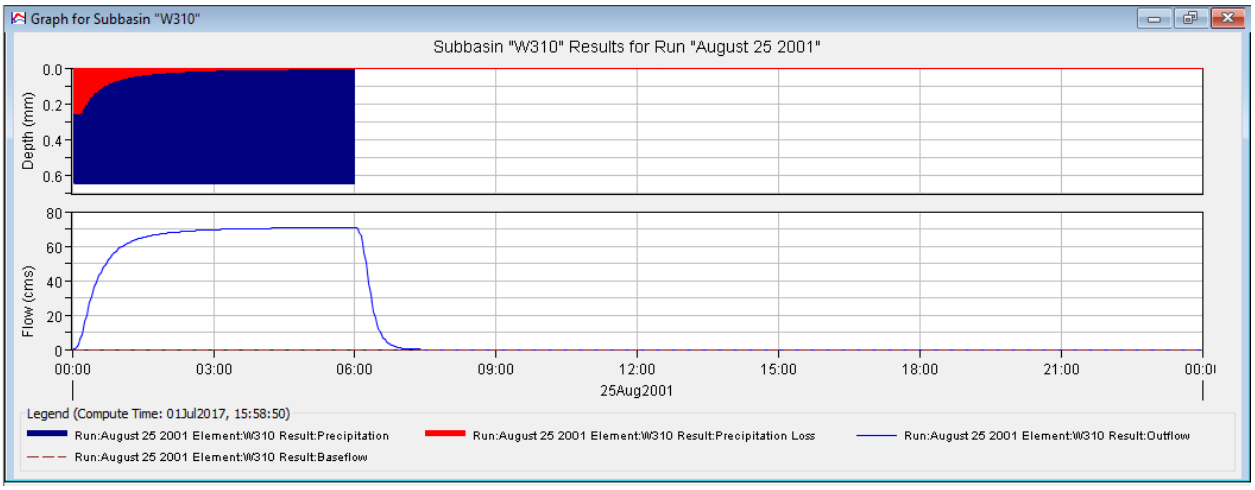


Figure 4.2 d: Sub Basin W310
Source: Authors Analysis (2017)

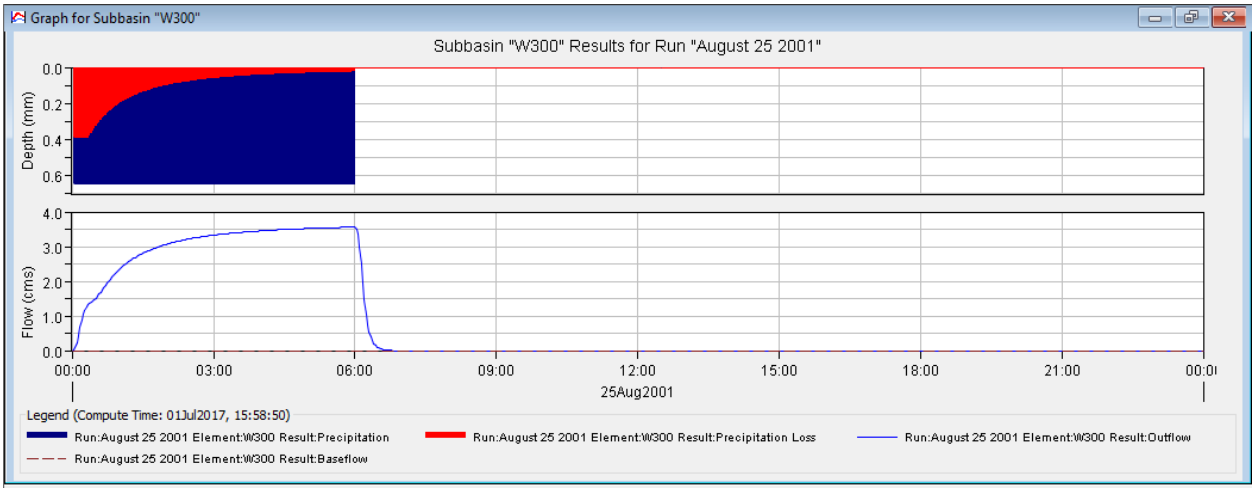


Figure 4.2 e: Sub Basin W300
Source: Authors Analysis (2017)

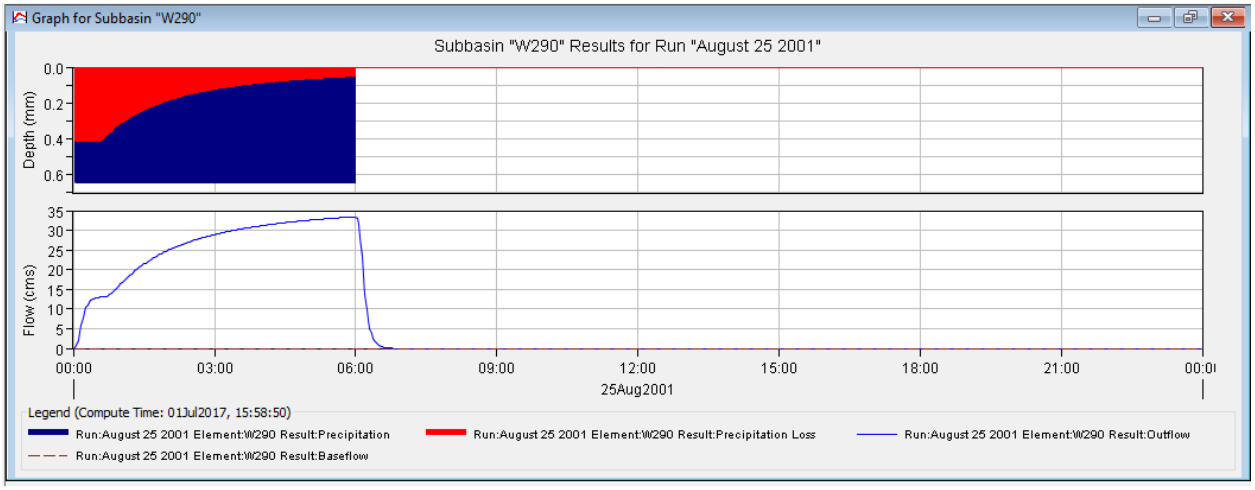


Figure 4.2 f: Sub Basin W290
Source: Authors Analysis (2017)

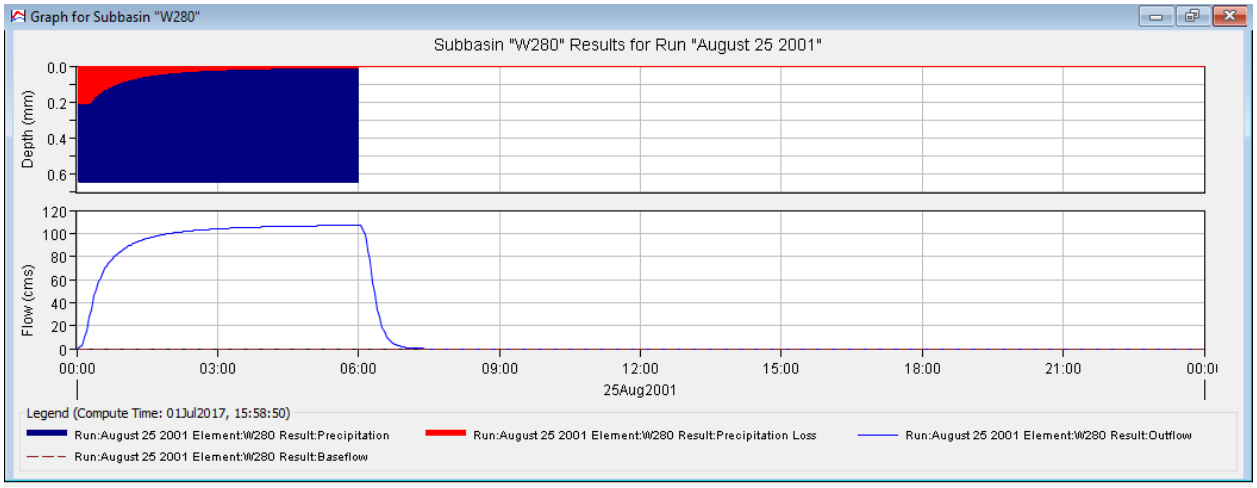


Figure 4.2 g: Sub Basin W280
Source: Authors Analysis (2017)

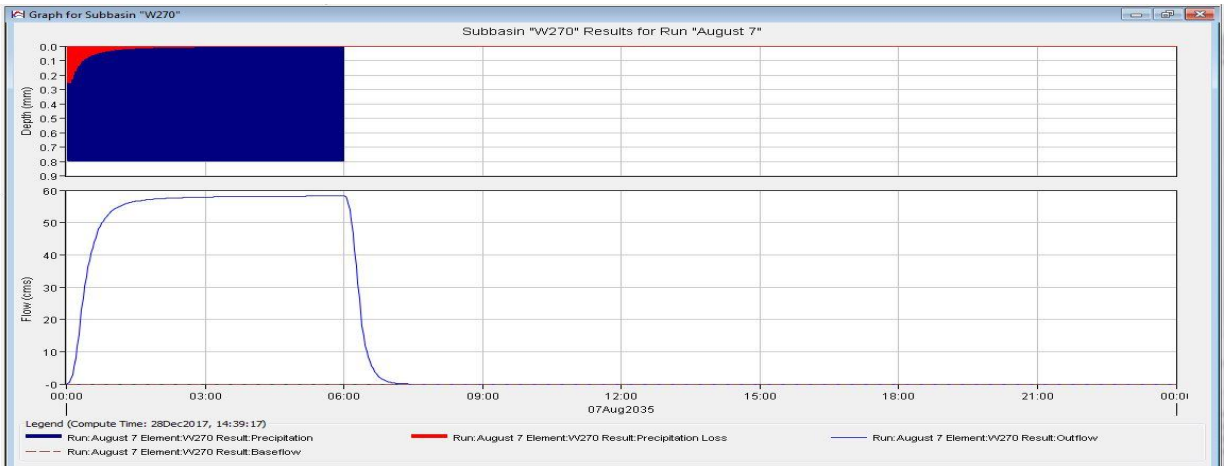


Figure 4.2 h: Sub Basin W270
Source: Authors Analysis (2017)

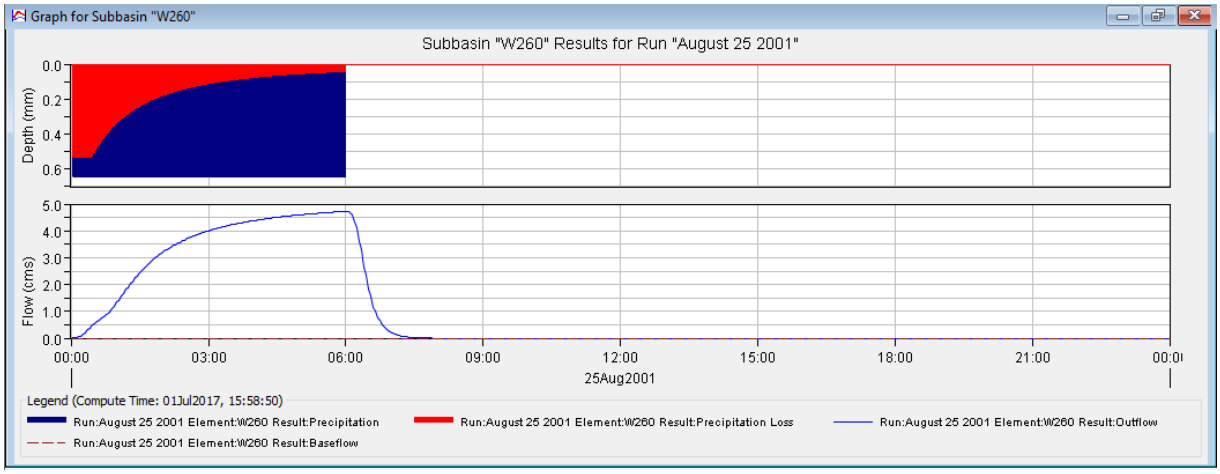


Figure 4.2 i: Sub Basin W260
Source: Authors Analysis (2017)

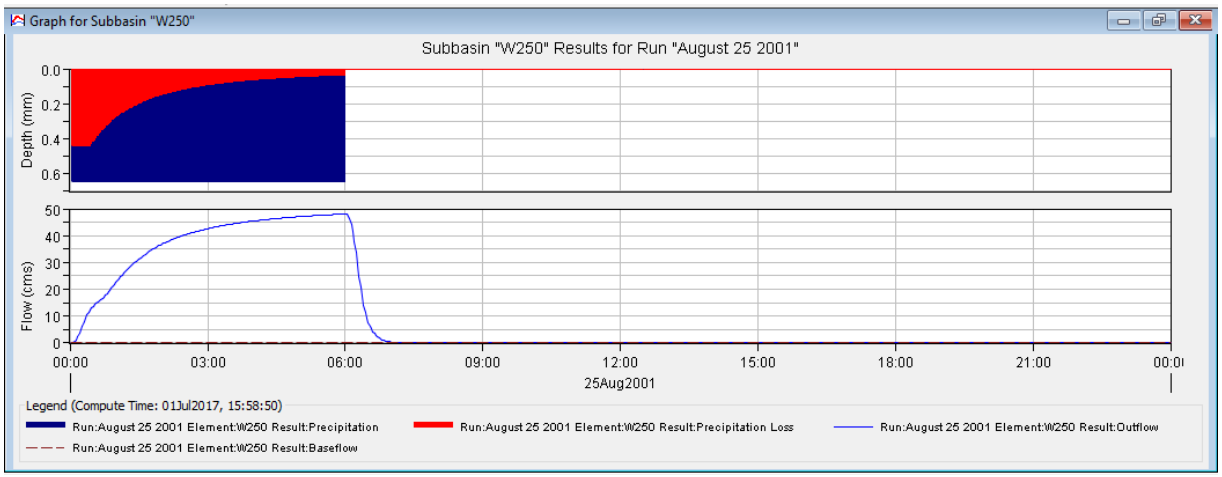


Figure 4.2 j: Sub Basin W250
Source: Authors Analysis (2017)

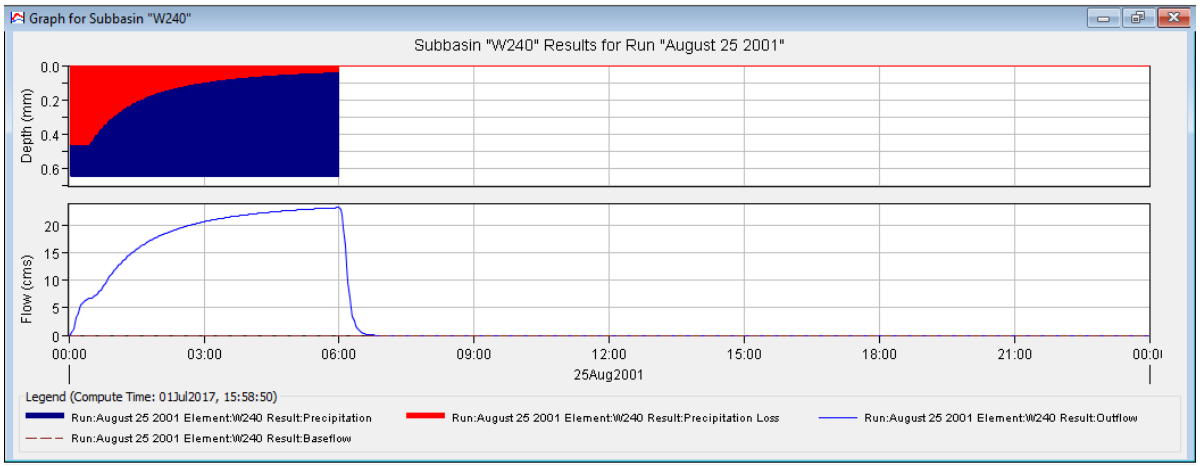


Figure 4.2 k: Sub Basin W240
Source: Authors Analysis (2017)

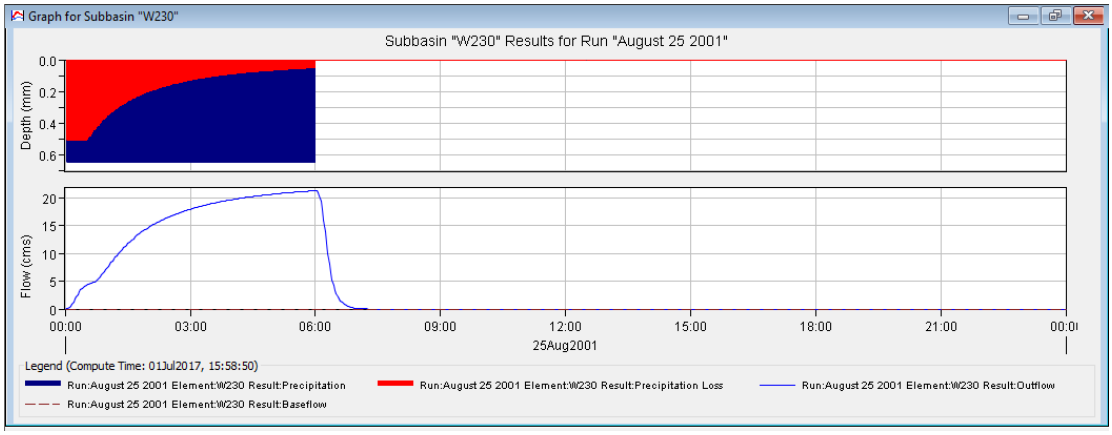


Figure 4.2 l: Sub Basin W230
Source: Authors Analysis (2017)

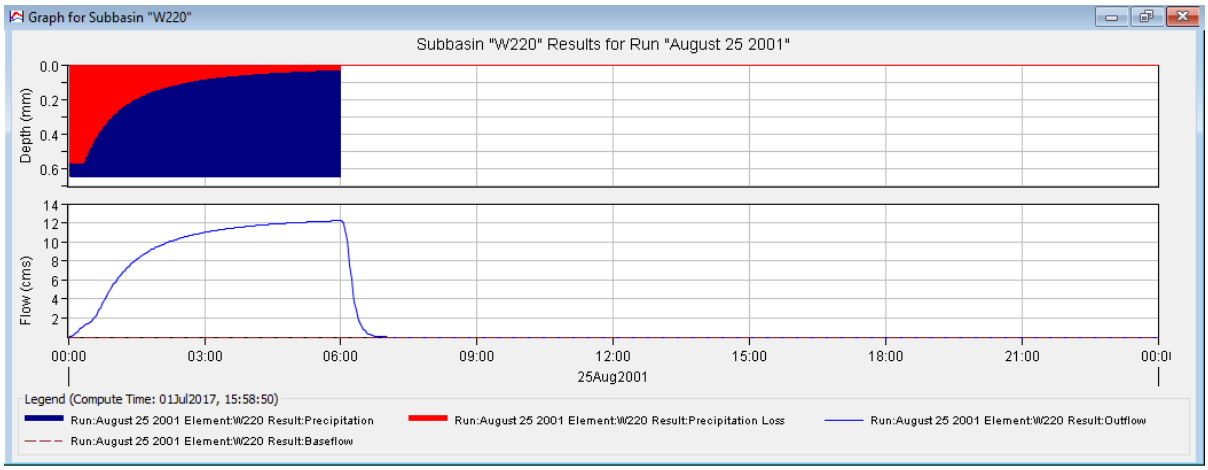


Figure 4.2 m: Sub Basin W220
Source: Authors Analysis (2017)

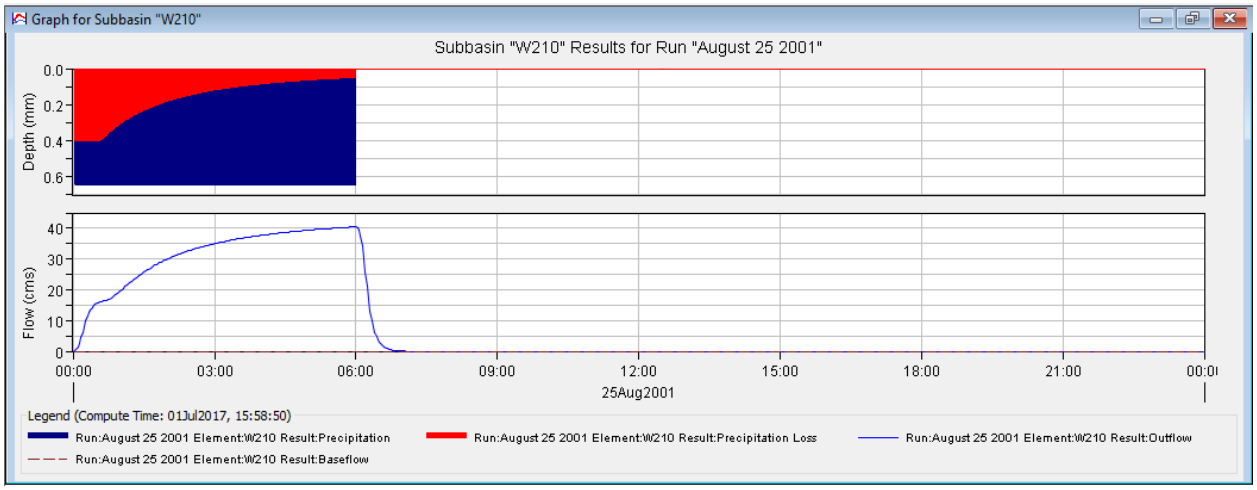


Figure 4.2 n: Sub Basin W210
Source: Authors Analysis (2017)

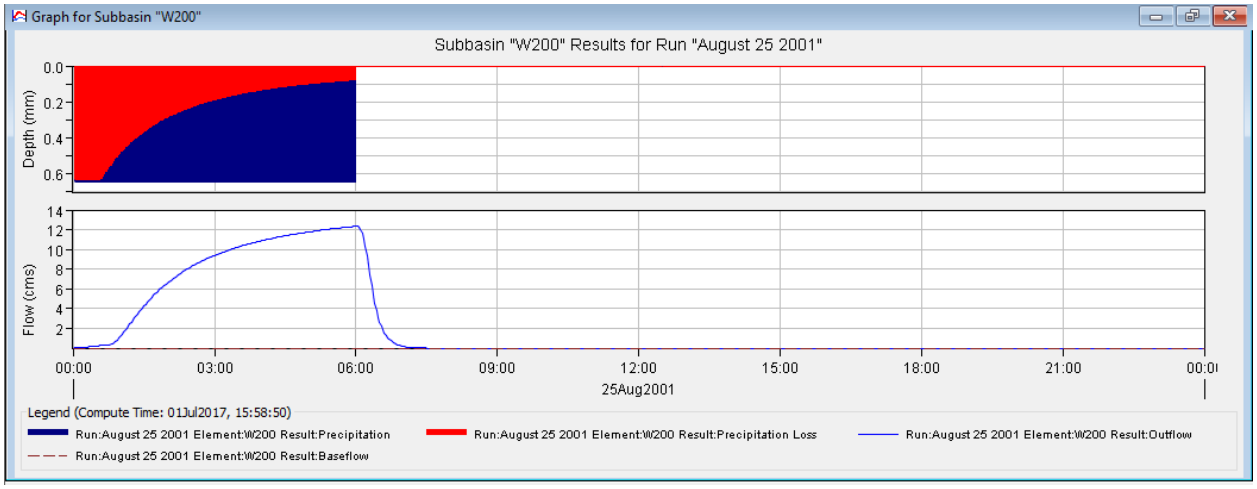


Figure 4.2 o: Sub Basin W200
Source: Authors Analysis (2017)

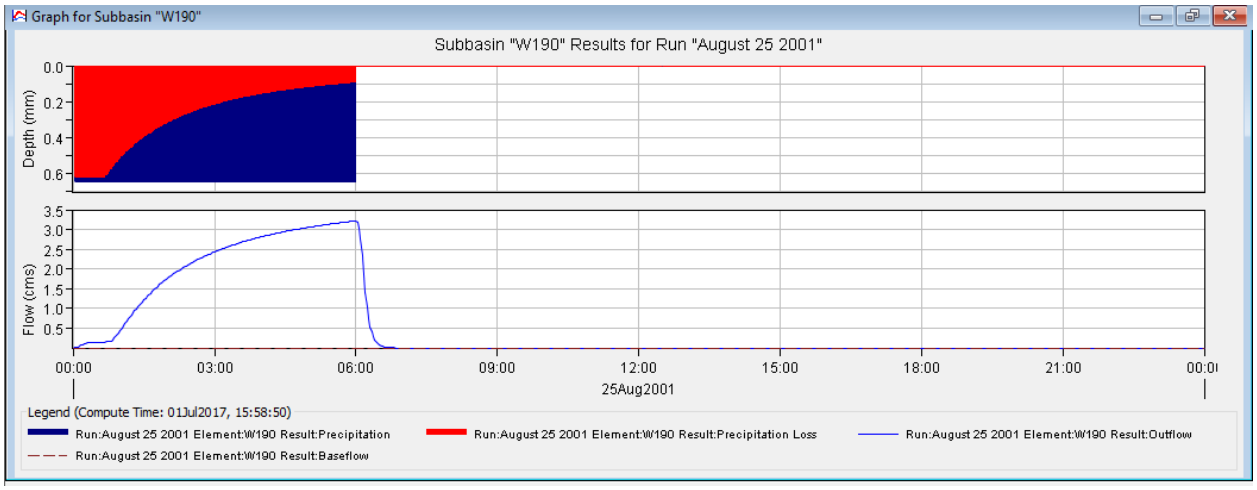


Figure 4.2 p: Sub Basin W190
Source: Authors Analysis (2017)

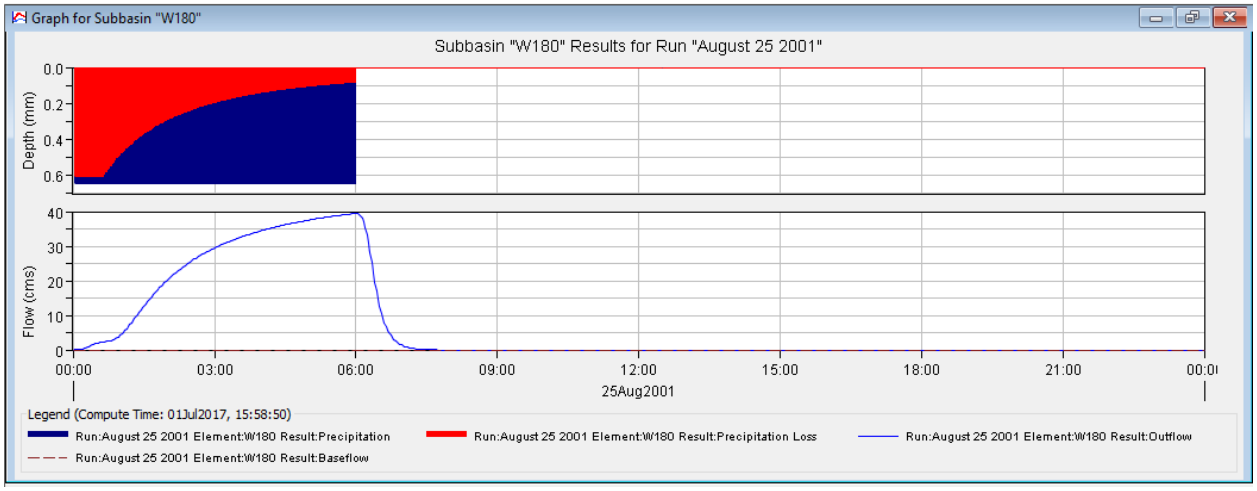


Figure 4.2 q: Sub Basin W180
Source: Authors Analysis (2017)

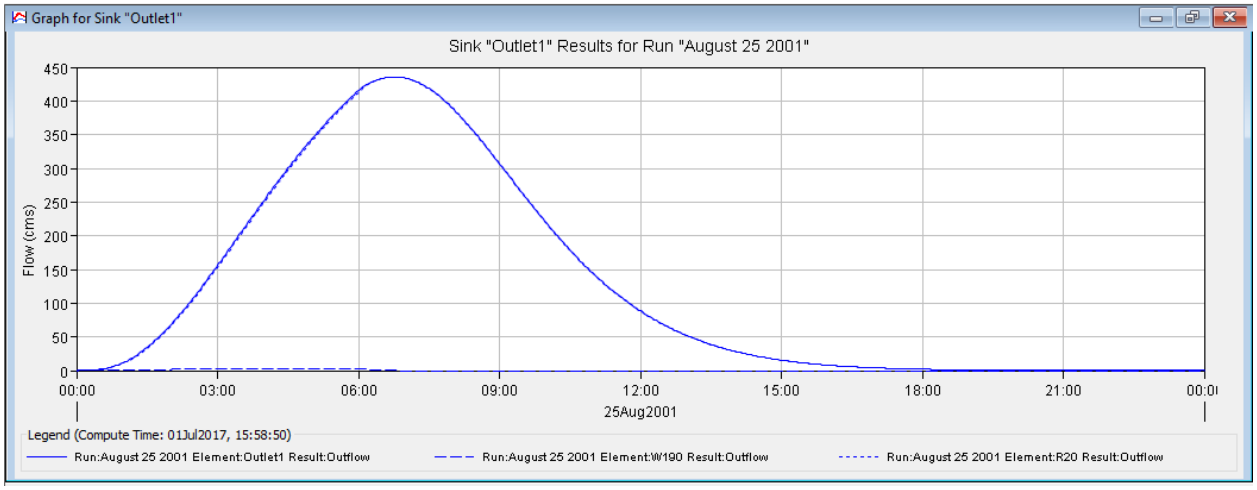


Figure 4.2 r: Outlet (Sink)
Source: Authors Analysis (2017)

4.3.1 Jakara Run off Discharge Simulation 2001

Sub –basins W310 has an area of 13.35200km^2 and a peak discharge of 70.2cm^3/sec. the total depth of run-off is 0.65mm^3, a total loss of 0.25mm^3 at the beginning of the storm event and reached field capacity within 3hrs 30mins. The basin covers a large part of Dala Local Government Area which is known to be a highly urbanized area with most part of it impervious.

Sub-basin W280 covers part of Nasarawa, Fagge and drains into Ungoggo LGA. It covers an area of 20.274km^2 and a peak discharge of 114.2cm^3/sec. The basin had a flow depth of 0.6mm^3 and a loss 0.2mm^3 over a period of 4hrs before reaching field capacity. This basin is also highly urbanized and large, thus the reason for the high flow rate.

Sub-basins W190 and W300 are the smallest in size with 0.70592 and 0.68870km^2 respectively. Even though W190 is slightly larger than W300 the peak discharge is less due to higher impervious surfaces. W300 had a peak discharge of 3.6cm^3/sec whileW190 has 3.4cm^3/sec with a loss of 0.4mm^3 and 0.62mm^3 over 6hrs respectively. This indicates less inundation for W190 as a result of being within the Ungoggo axis with more pervious surface and high discharge for W300 which is situated within Fagge area and highly developed. The Outlet of the entire basin has a peak discharge of 446.2cm^3/sec. the findings is in agreement with that of Ishman (2014) that increased development of impervious layers increases flow discharge of a basin.

4.3.2 JakaraRun off Discharge Simulation 2012

The trend of peak discharge of the various sub-basins resembles that of 2001 but with an increase in the number of sub-basins with higher peak discharge of above 55cm^3/sec. the

highest was also observed in W280 with 137.2cm^3/sec.(see fig 4.), this is as result of an increase in impervious layers in the sub-basins that had lower peak discharge in 2001(Figure 4.1). Sub-basins W310, W250, and W330 had peaks of 84.2, 61.0 and 59.8cm^3/sec which is quite higher than that of 2001 both in quantity and number of basins with such discharges, the outlet's peak discharge is 585.2cm^3/sec, this shows an increase in discharge of 130cm3/sec although with a lower observed rainfall intensity. W300 and W190 had peaks of 4.7 and 4.2cm^3/sec which shows a slight increase in volume compared to 2001. The outcome coincides with that of Screenivasulu and Bhaskar (2010) where the study noticed a sharp increase in discharge of developed small basins and high incidences of flash floods.

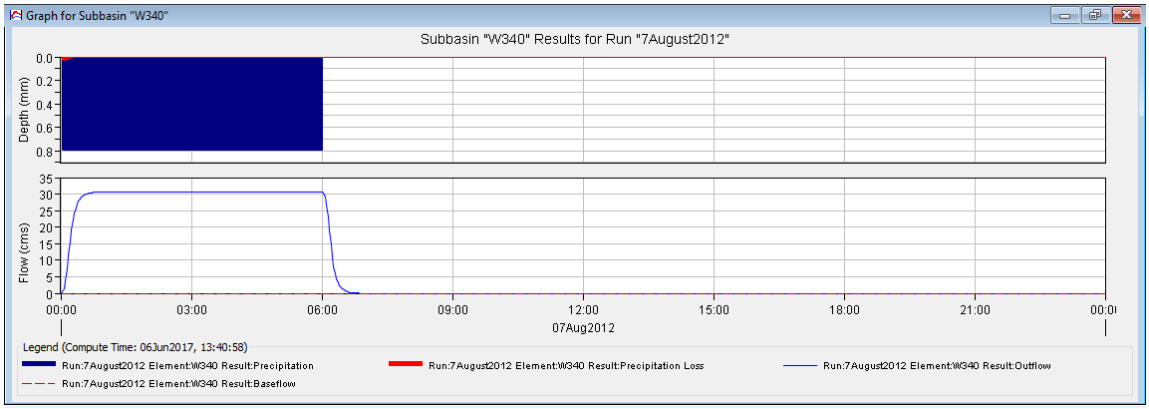


Figure 4.3 a: Sub Basin W340
Source: Authors Analysis (2017)

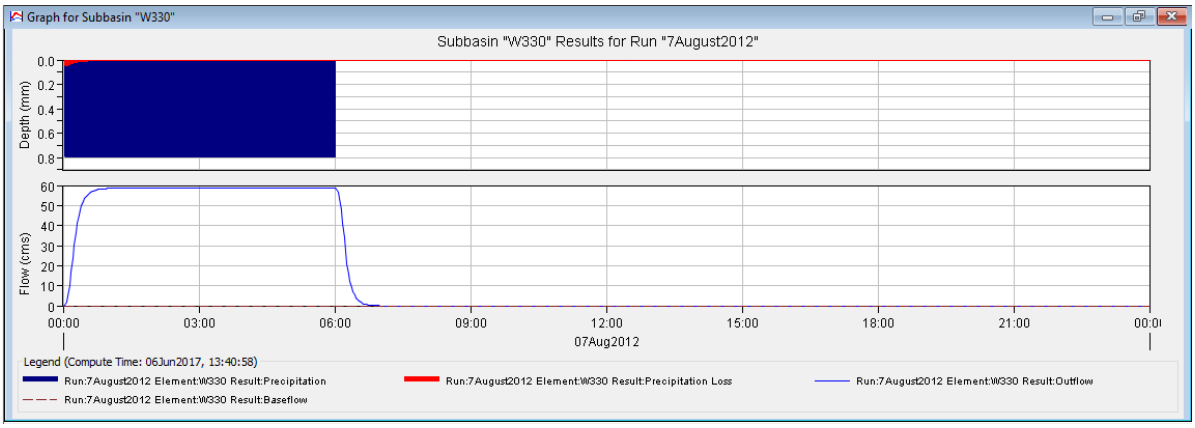


Figure 4.3 b: Sub Basin W330
Source: Authors Analysis (2017)

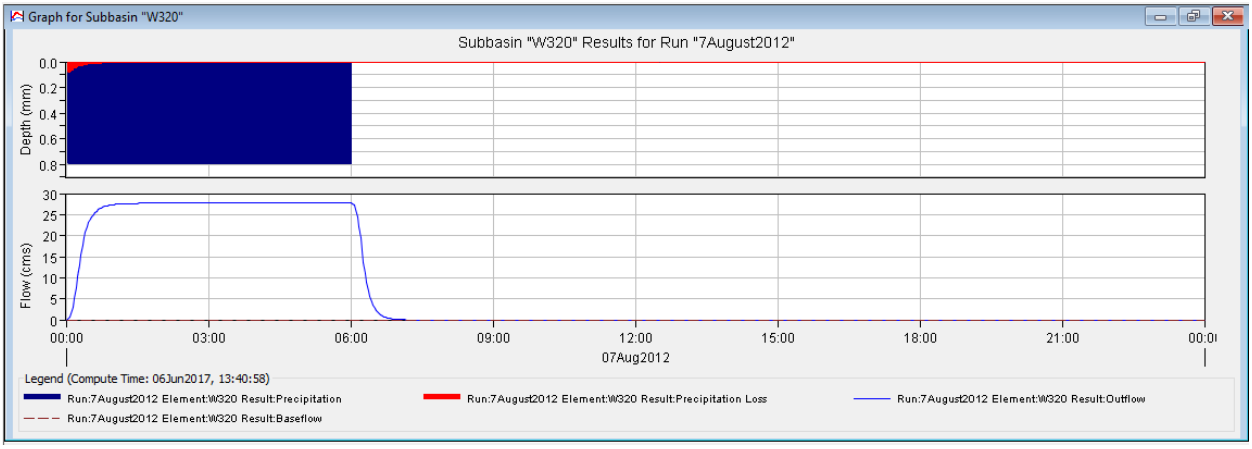


Figure 4.3 c: Sub Basin W320
Source: Authors Analysis (2017)

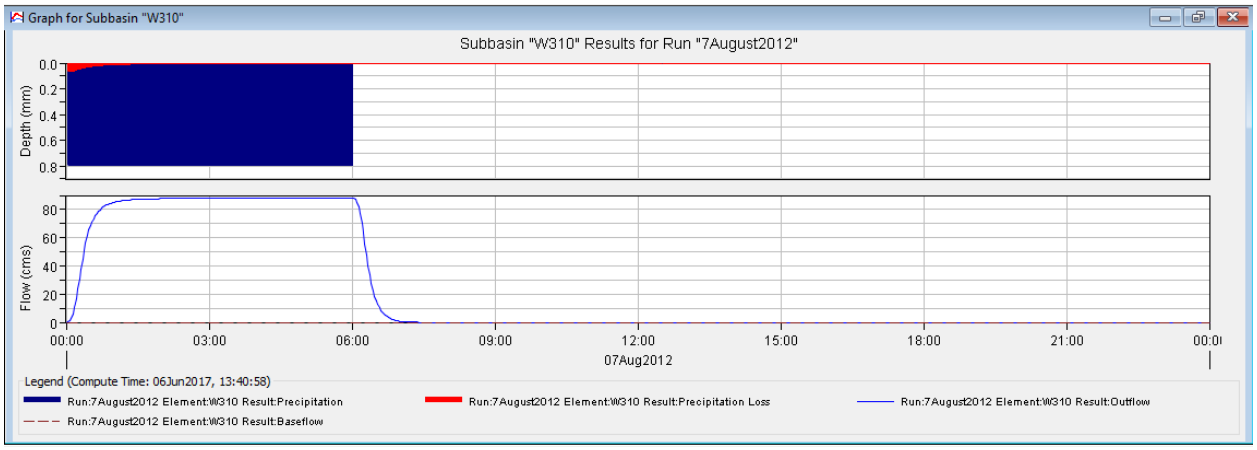


Figure 4.3 d: Sub Basin W310
Source: Authors Analysis (2017)

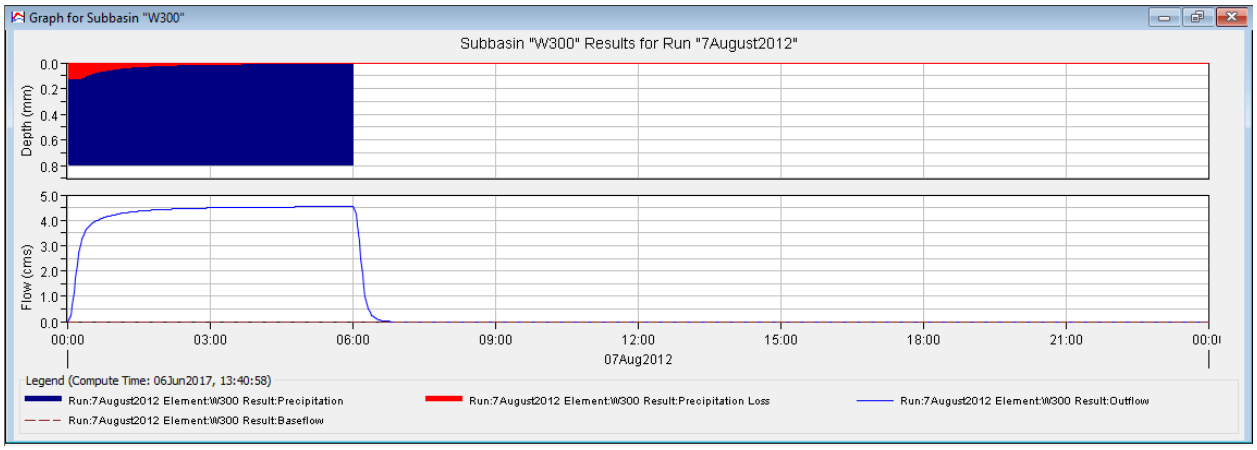


Figure 4.3 e: Sub Basin W300
Source: Authors Analysis (2017)

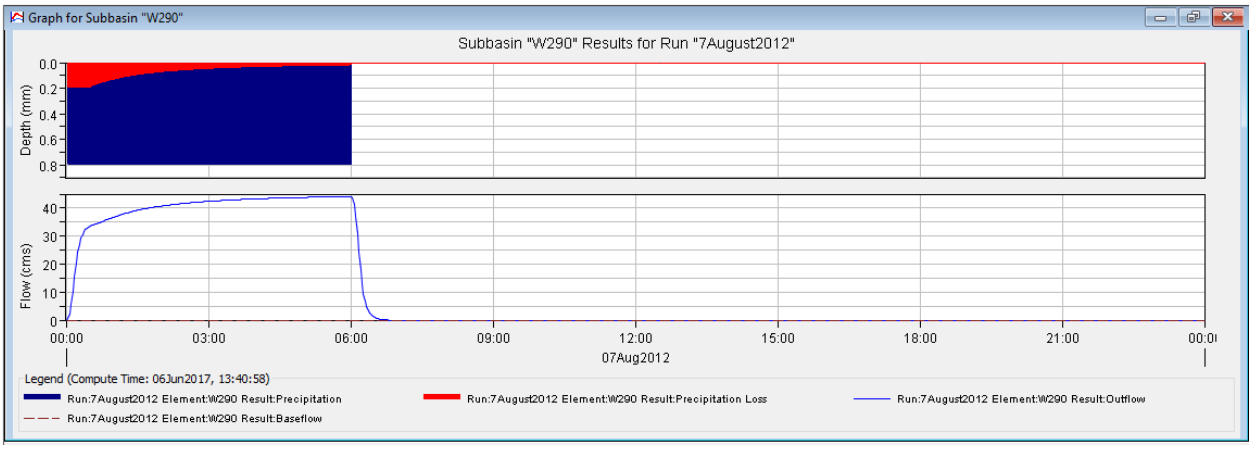


Figure 4.3 f: Sub Basin W290
Source: Authors Analysis (2017)

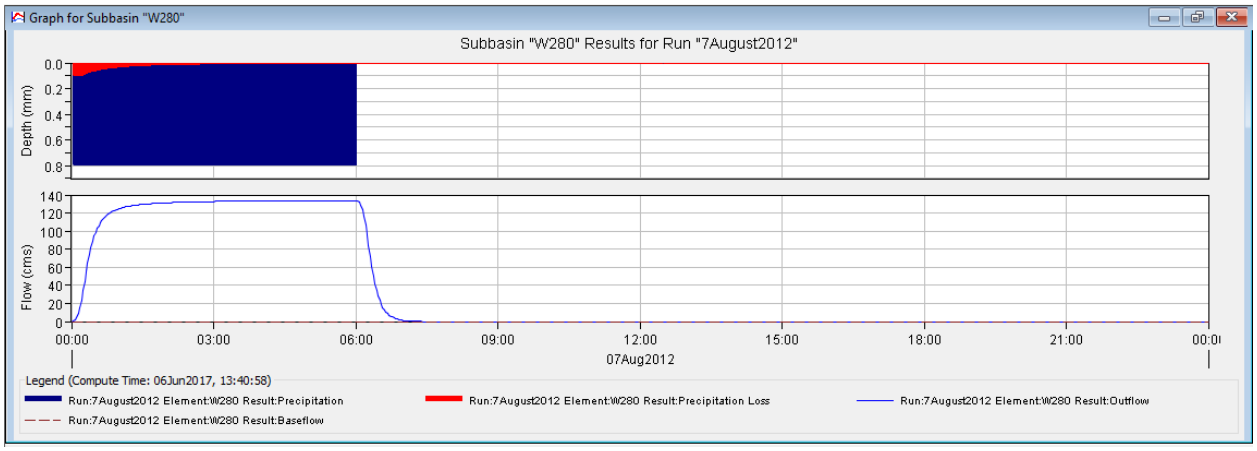


Figure 4.3 g: Sub Basin W280
Source: Authors Analysis (2017)

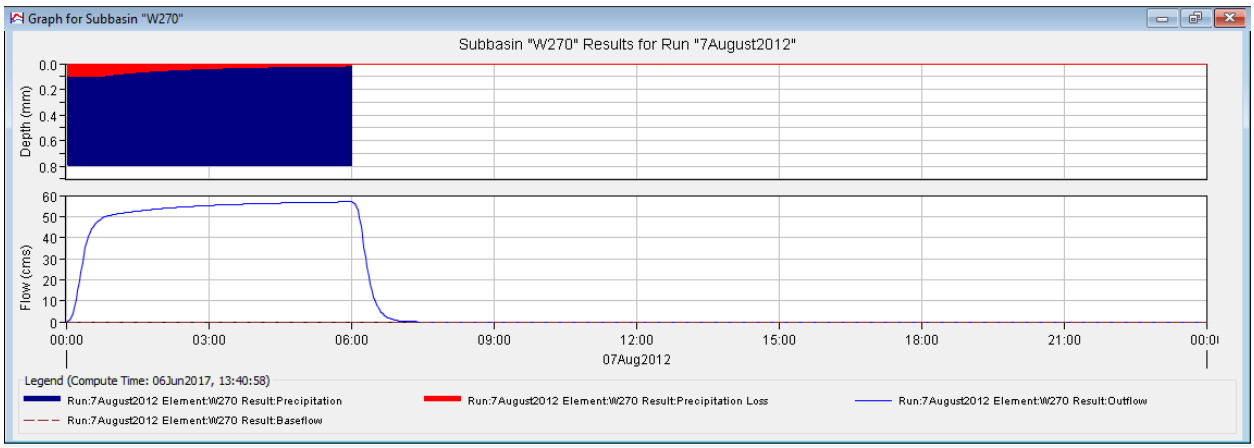


Figure 4.3 h: Sub Basin W270
Source: Authors Analysis (2017)

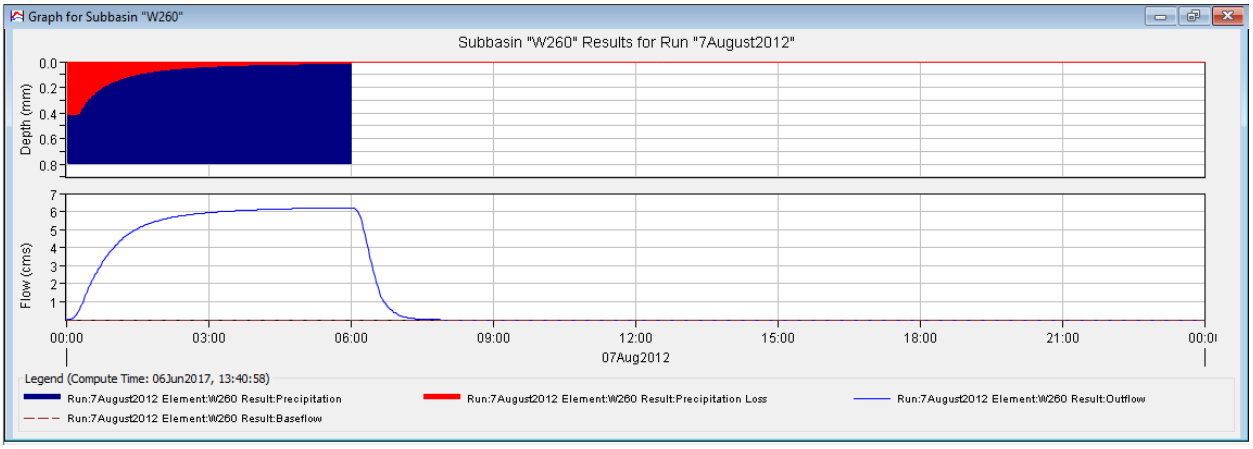


Figure 4.3i: Sub Basin W260
Source: Authors Analysis (2017)

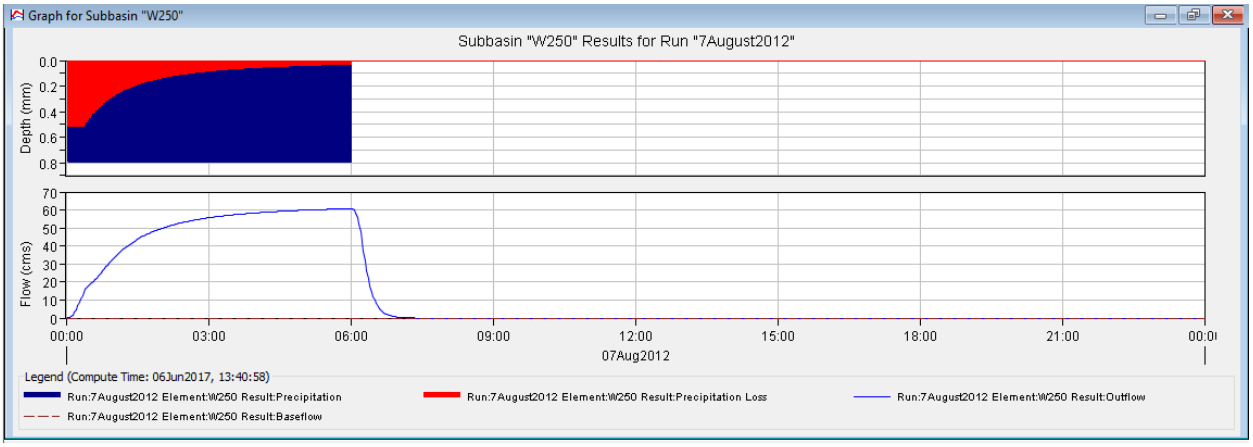


Figure 4.3 j: Sub Basin W250
Source: Authors Analysis (2017)

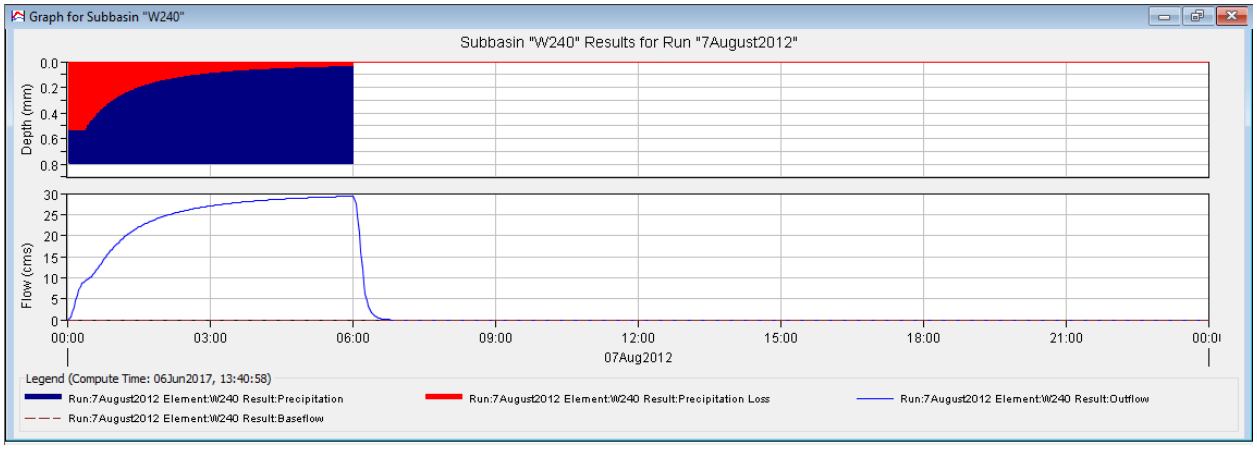


Figure 4.3 k: Sub Basin W240
Source: Authors Analysis (2017)

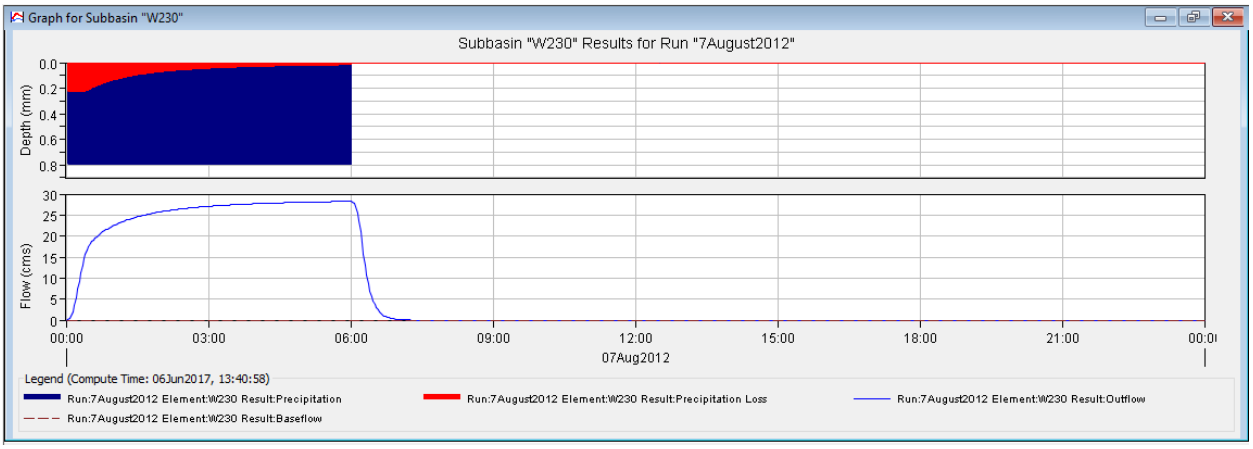


Figure 4.3 l: Sub Basin W230
Source: Authors Analysis (2017)

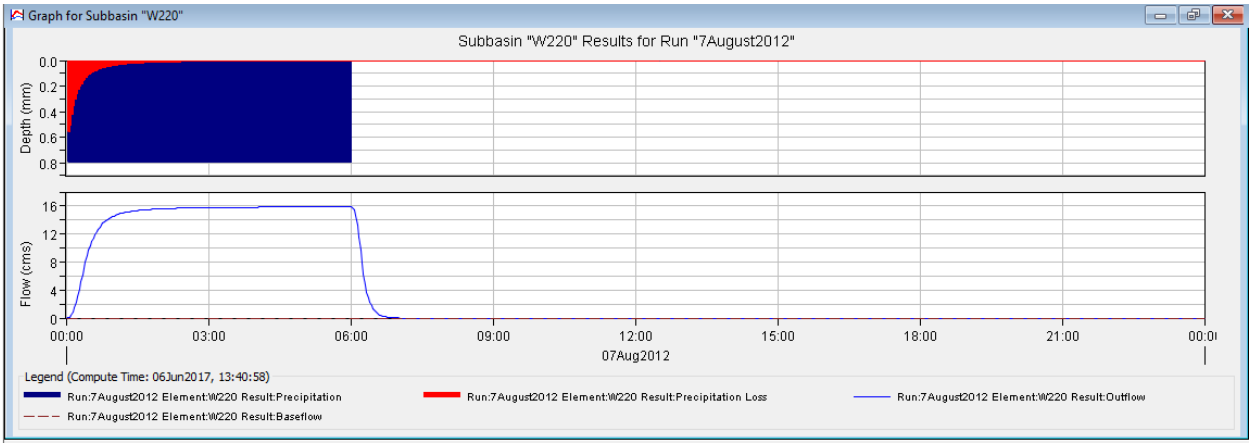


Figure 4.3 m: Sub Basin W220
Source: Authors Analysis (2017)

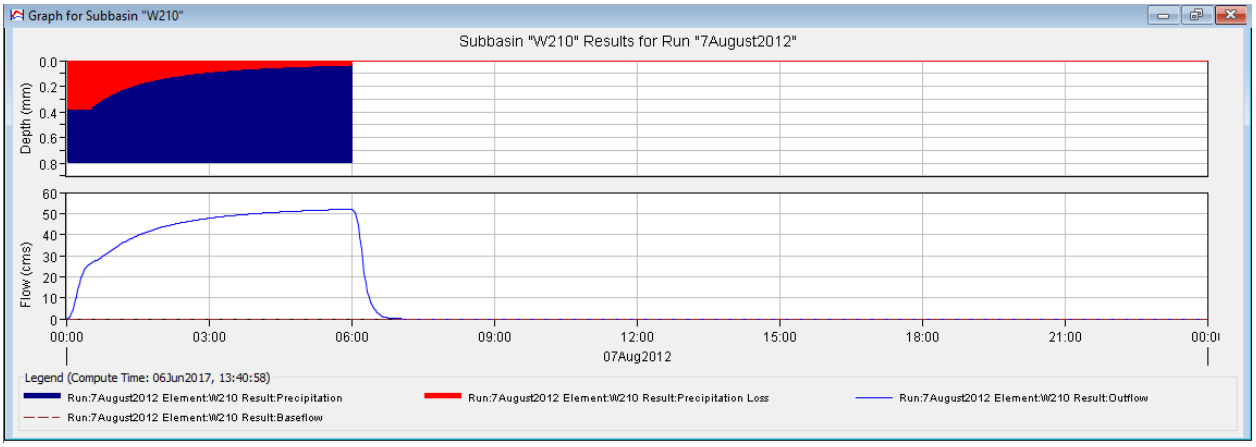


Figure 4.3n: Sub Basin W210
Source: Authors Analysis (2017)

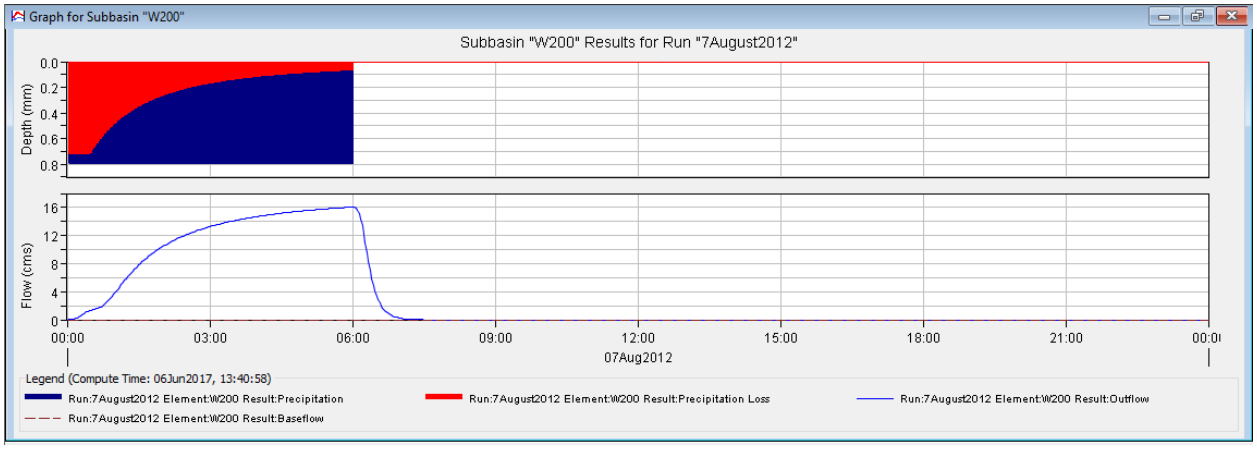


Figure 4.3 o: Sub Basin W200
Source: Authors Analysis (2017)

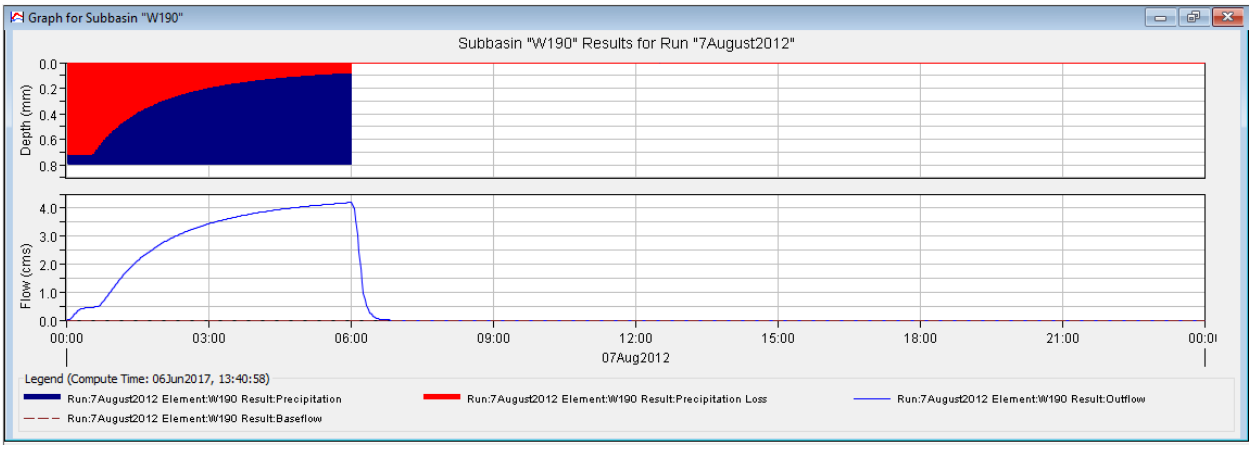


Figure 4.3 p: Sub Basin W190
Source: Authors Analysis (2017)

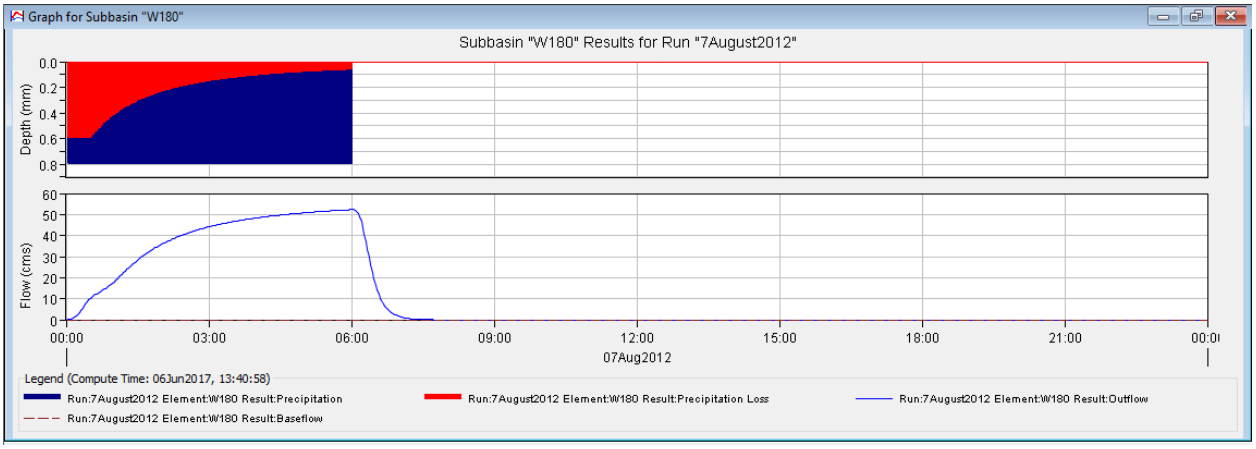


Figure 4.3 q: Sub Basin W180
Source: Authors Analysis (2017)

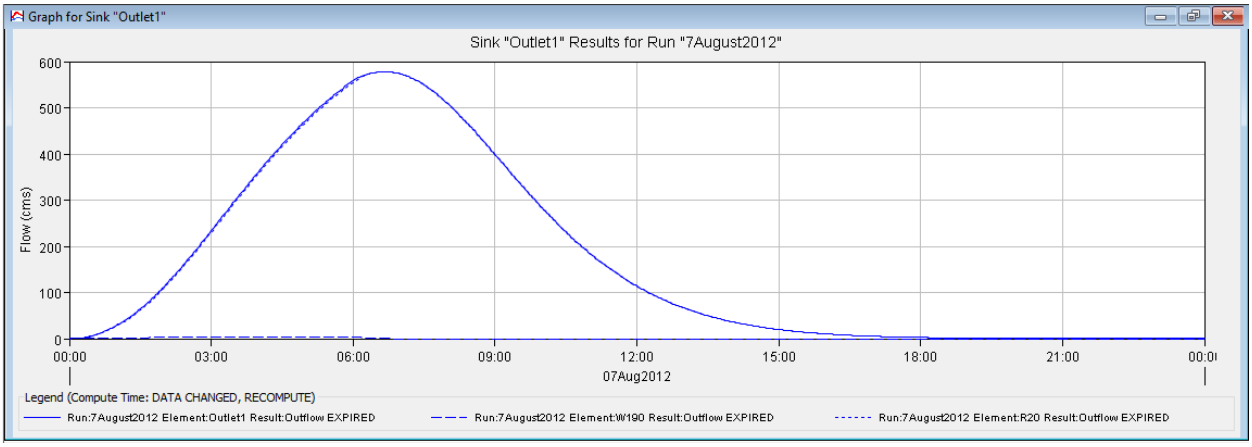


Figure 4.3 r: Outlet
Source: Authors Analysis (2017)

4.3.3 Jakara Run off Discharge Simulation 2035 Forecast

In 2035, using the same rainfall amount of 2012 but projected land use and land cover values, gave a slight rise in peak discharge for few sub-basins especially the less urbanized areas in 2012. There was an increase in peak discharge in sub-basins W310, W340, W180, the outlet W190, W250 and W210 with 88.3, 30.7, 56.4, 609.7, 4.7 cm^3/sec., likewise the loss was also low, (see Figure 4.) these reflects the influence of increased imperviousness of the surface. This was also observed in the study of Samarasingh et.al. (2010), Alghamand et.al. (2010) and Garcia-Pintado (2013), where an increase in impervious surfaces raised the amount of run-off, reduced the time of peak discharge and increased the extent and velocity of flood waters. As revealed, flooding will increase in extent and depth within sub-basins that were not affected in 2012 due to an increase in the extent of built up areas (see Figure 4.1g, 4.1h).

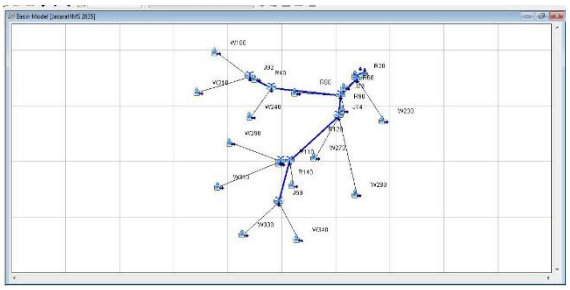


Figure 4.4 a: Jakara Drainage Basin Model
Source: Authors Analysis (2017)

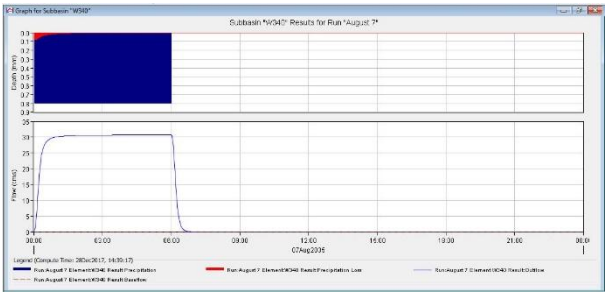


Figure 4.4e: Sub Basin W340
Source: Authors Analysis (2017)

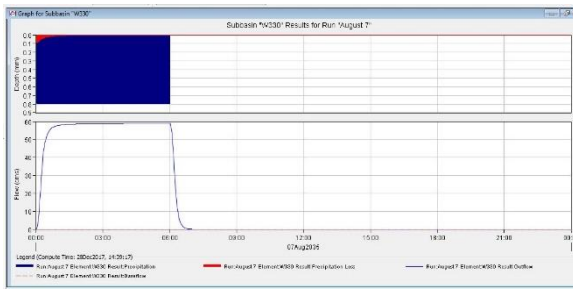


Figure 4.4 b: Sub Basin W330
Source: Authors Analysis (2017)

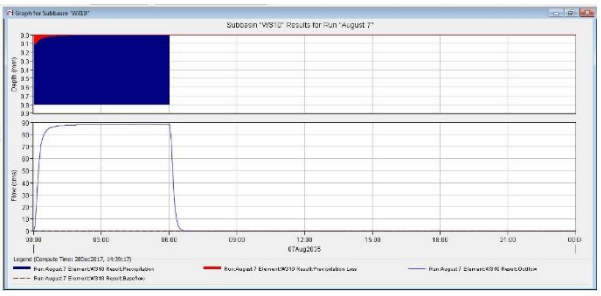


Figure 4.4f: Sub Basin W310
Source: Authors Analysis (2017)

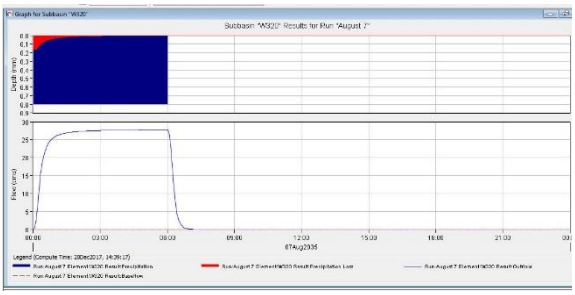


Figure 4.4 c: Sub Basin W320
Source: Authors Analysis (2017)

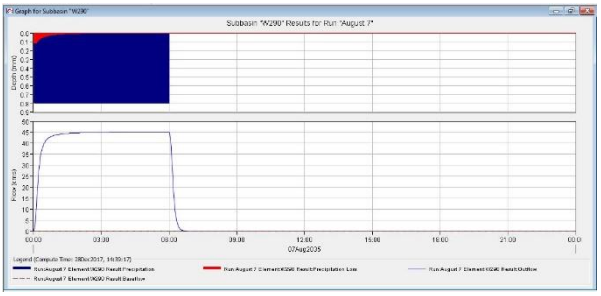


Figure 4.4g: Sub Basin W290
Source: Authors Analysis (2017)

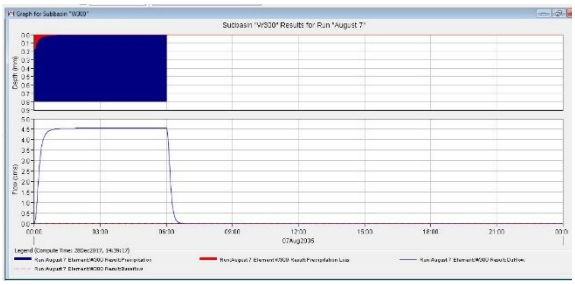


Figure 4.4 d: Sub Basin W300
Source: Authors Analysis (2017)

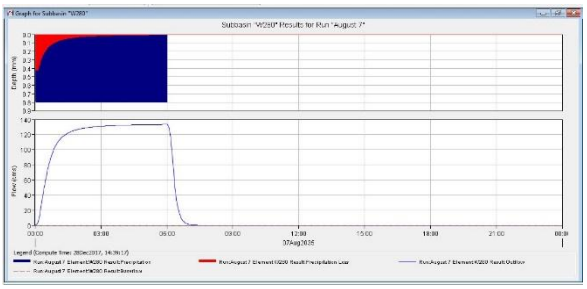


Figure 4.4h: Sub Basin W280
Source: Authors Analysis (2017)

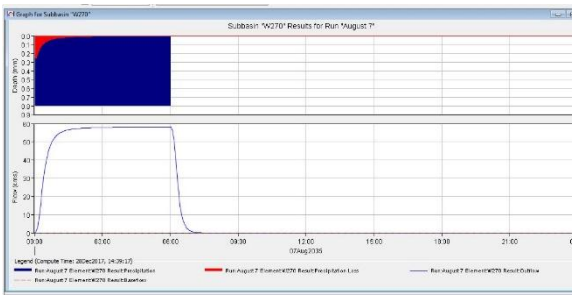


Figure 4.4i: Sub Basin W270
Source: Authors Analysis (2017)

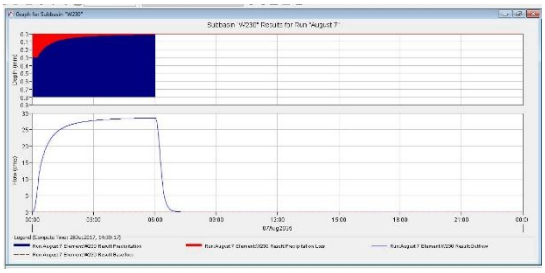


Figure 4.4m: Sub Basin W230
Source: Authors Analysis (2017)

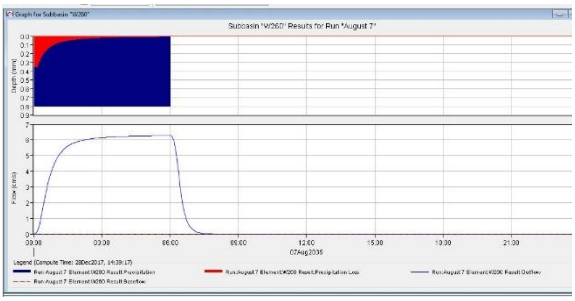


Figure 4.4j: Sub Basin W260
Source: Authors Analysis (2017)

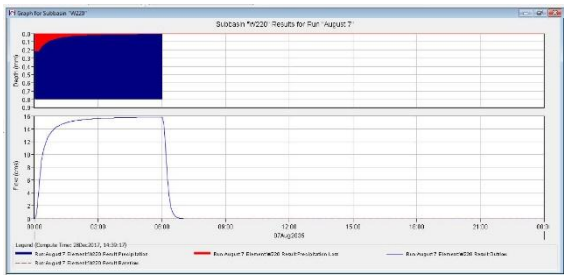


Figure 4.4n: Sub Basin W220
Source: Authors Analysis (2017)

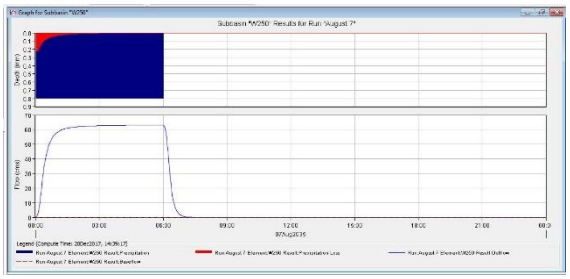


Figure 4.4k: Sub Basin W250
Source: Authors Analysis (2017)

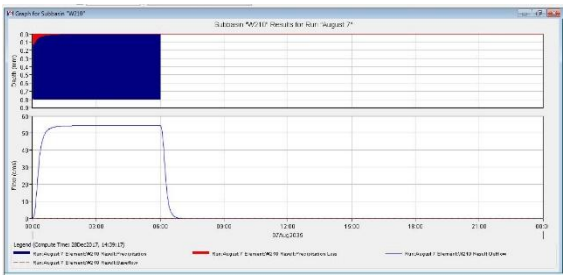


Figure 4.4o: Sub Basin W210
Source: Authors Analysis (2017)

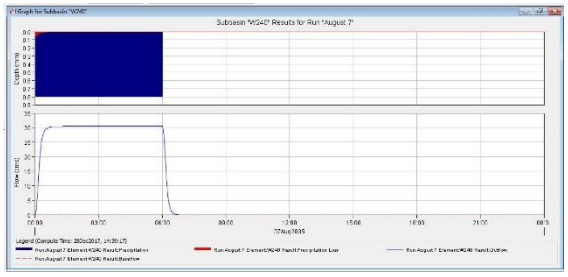


Figure 4.4l: Sub Basin W240
Source: Authors Analysis (2017)

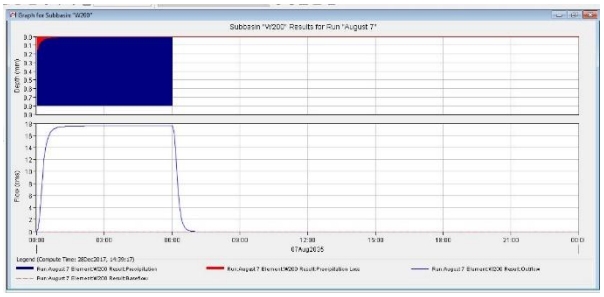


Figure 4.4p: Sub Basin W200
Source: Authors Analysis (2017)

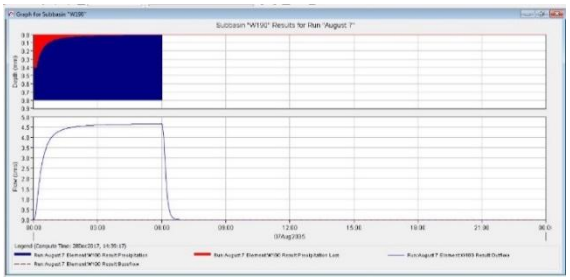


Figure 4.4q: Sub Basin W190
Source: Authors Analysis (2017)

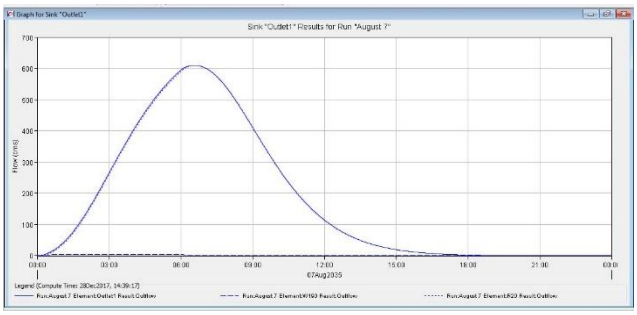


Figure 4.4s: Outlet
Source: Authors Analysis (2017)

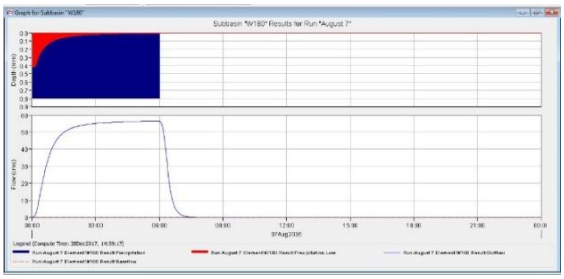


Figure 4.4r: Sub Basin W180
Source: Authors Analysis (2017)

4.3.4 Chalawa Run off Discharge Simulation 2001

This presents the result and discussion of the amount of runoff in Chalawa drainage basin of 2001, 2012 and 2035. The basin has an area of 104.9km^2 and 15 sub-basins, the rainfall event of 2001 that occurred on the 25th of July had a peak discharge of 163mm^3/sec while that of 7th August 2012 was 143mm^3/sec, which was also replicated for 2035.

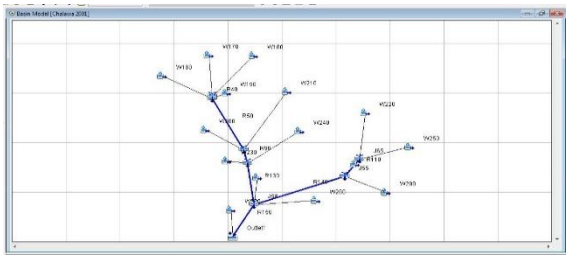


Figure 4.5 a: Chalawa Drainage Basin
Source: Authors Analysis (2017)

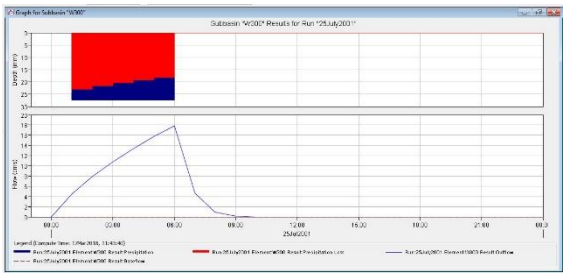


Figure 4.5b: Sub Basin W300
Source: Authors Analysis (2017)

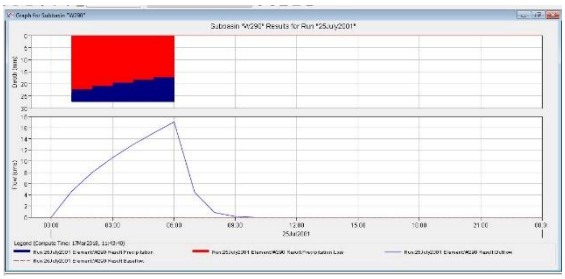


Figure 4.5c: Sub Basin W290
Source: Authors Analysis (2017)

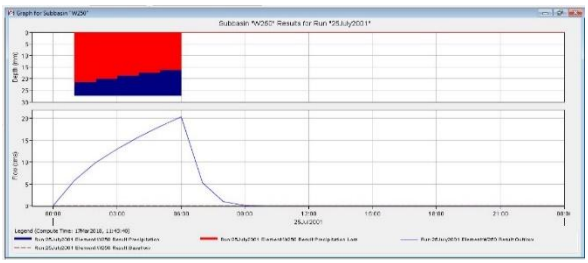


Figure 4.5g: Sub Basin W250
Source: Authors Analysis (2017)

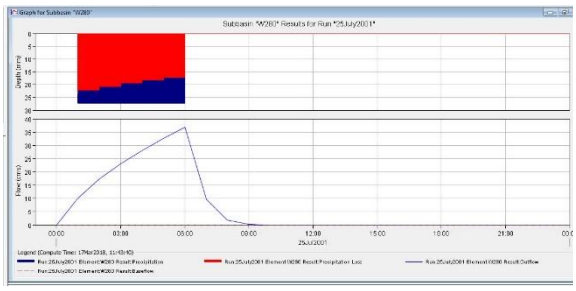


Figure 4.5d: Sub Basin W280
Source: Authors Analysis (2017)

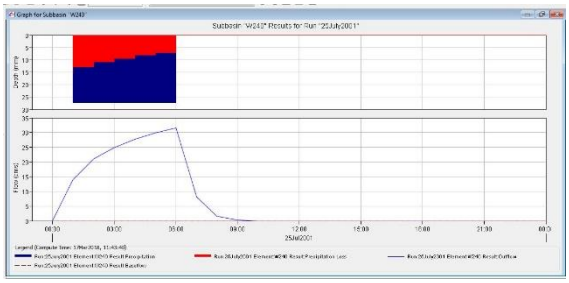


Figure 4.5h: Sub Basin W240
Source: Authors Analysis (2017)

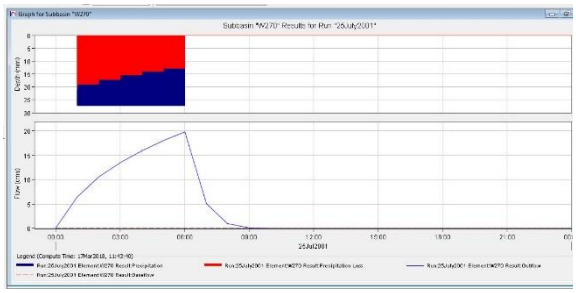


Figure 4.5e: Sub Basin W270
Source: Authors Analysis (2017)

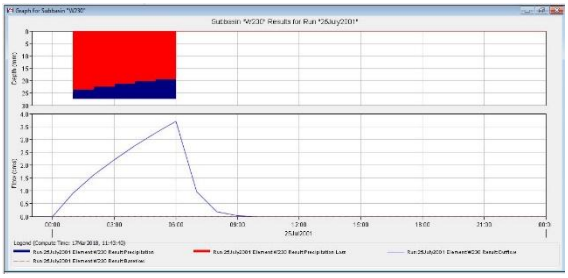


Figure 4.5i: Sub Basin W230
Source: Authors Analysis (2017)

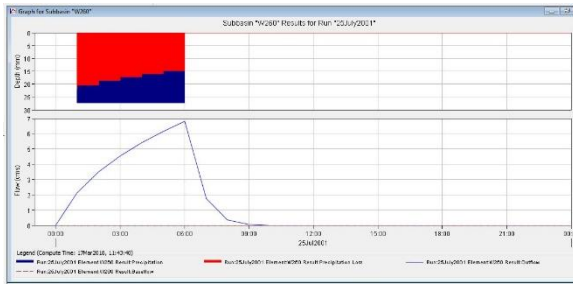


Figure 4.5f: Sub Basin W260
Source: Authors Analysis (2017)

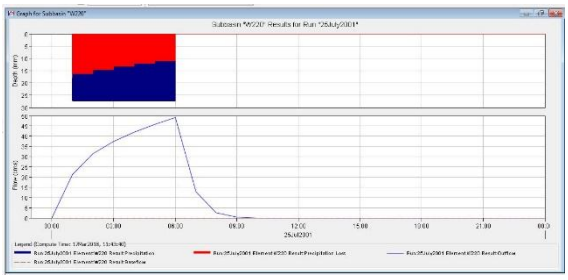


Figure 4.5j: Sub Basin W220
Source: Authors Analysis (2017)

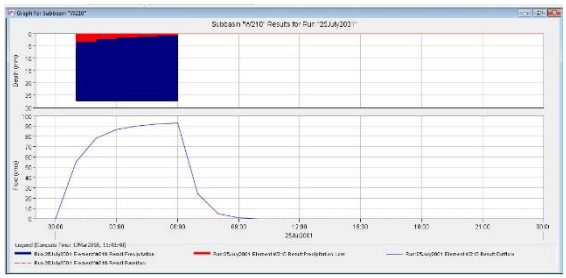


Figure 4.5k: Sub Basin W210
Source: Authors Analysis (2017)

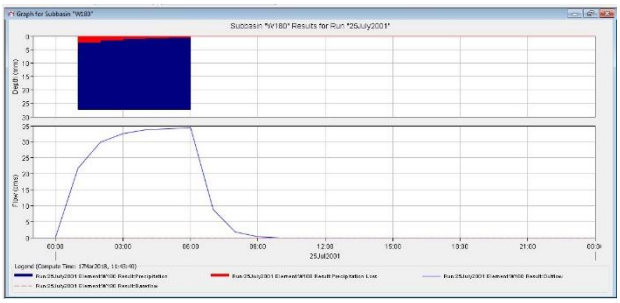


Figure 4.5n: Sub Basin W180
Source: Authors Analysis (2017)

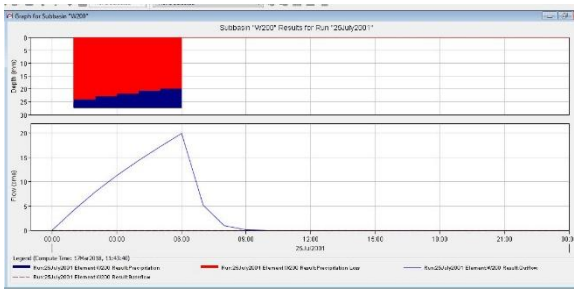


Figure 4.5l: Sub Basin W200
Source: Authors Analysis (2017)

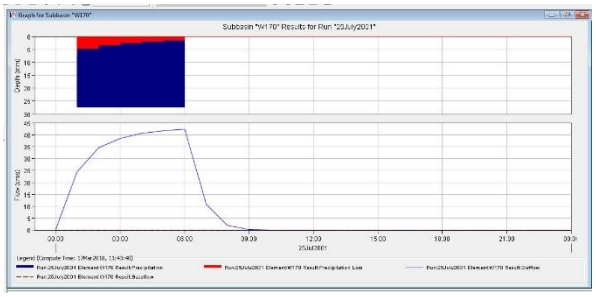


Figure 4.5o: Sub Basin W170
Source: Authors Analysis (2017)

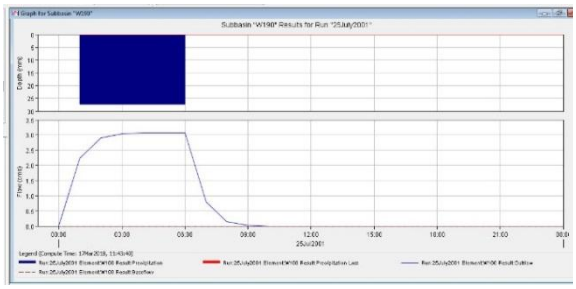


Figure 4.5m: Sub Basin W190
Source: Authors Analysis (2017)

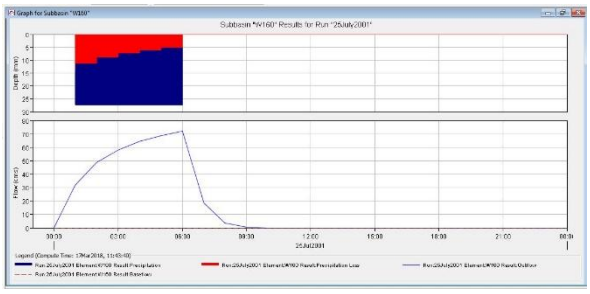


Figure 4.5p: Sub Basin W160
Source: Authors Analysis (2017)

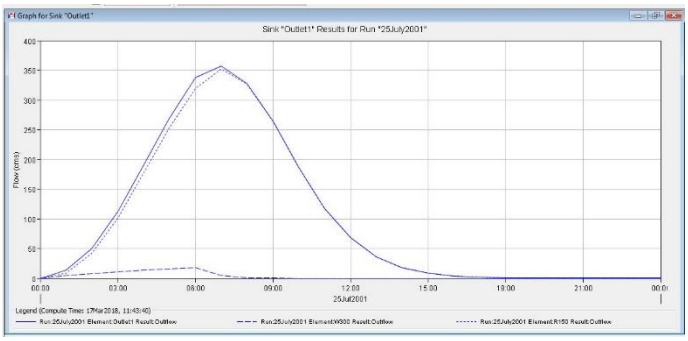


Figure 4.5q: Outlet
Source: Authors Analysis (2017)

Sub-basin W210 has an area of 12.7km^2 and a peak discharge of 93.2cm^3/sec and a 25mm^{3}depth of runoff with a loss of 5mm^3 within 2hrs from onset of the rainfall likewise W160 had a peak discharge of 72.2cm^3/sec within 3hrs with an area of 11.9km^2 this basin had a loss of 11mm^3 over a span of 6hrs. The sub-basins with the lowest discharge are W190 and W250 with a peak discharge of 3.1 and 3.7cm^3/sec respectively. Theses sub-basins are also highly urbanized but with small area coverages thus the reason for lower discharge. It was also observed that large sub-basins with extensive impervious surface generated more run-offs and flooding than the smaller basins. This results disputes that of Bhatt (2012) which observed that smaller basins had higher peak discharge than the larger basin, but this agrees with the findings of Ojigi and Shaba(2013) which revealed that larger basins have higher peak discharge and run-off loss.

4.3.5 Chalawa Run off Discharge Simulation 2012

On the 7th of August 2012 the basin observed a rainfall event with a peak discharge of 143mm^{3}which is less than that of 2001. The increase in discharge was mostly observed in areas that had changes in land use and land cover. Sub- basin W160, W200, W220, W230, and W280 increased in the amount and depth of run-off compared to 2001 with (80, 61, 60, 11, and 81) cm^3/sec respectively. The amount of run-off loss also increased as a result of change in LULC (see figure 4.1b), W160, W220,W200 and W210 had losses of 0.1mm^3 within the first 2hrs rainfall event before reaching field capacity. A similar result was observed by Bandaragoda (2008) in a study on prediction of run-off of ungauged basins.

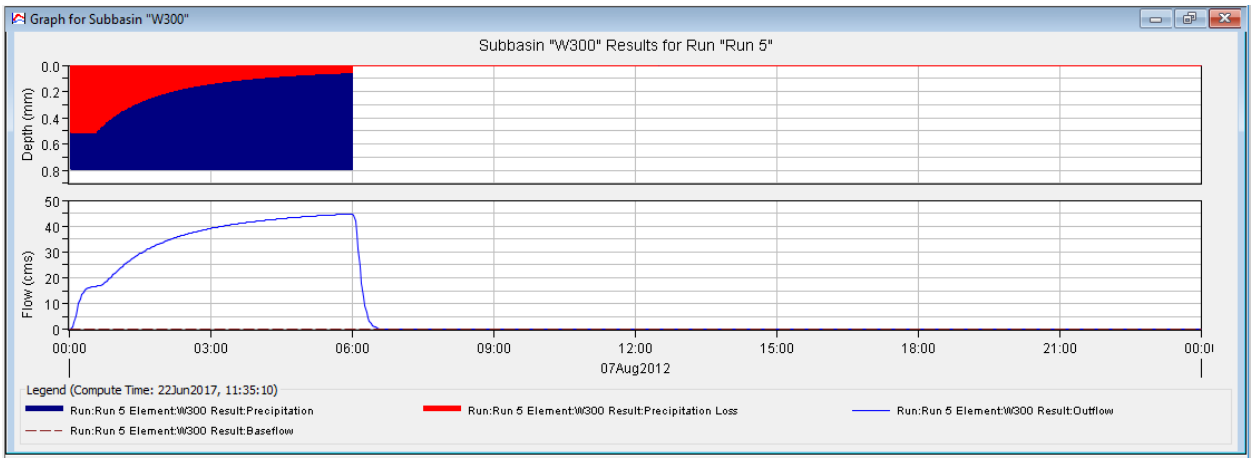


Figure 4.6 a: Sub Basin W300
Source: Authors Analysis (2017)

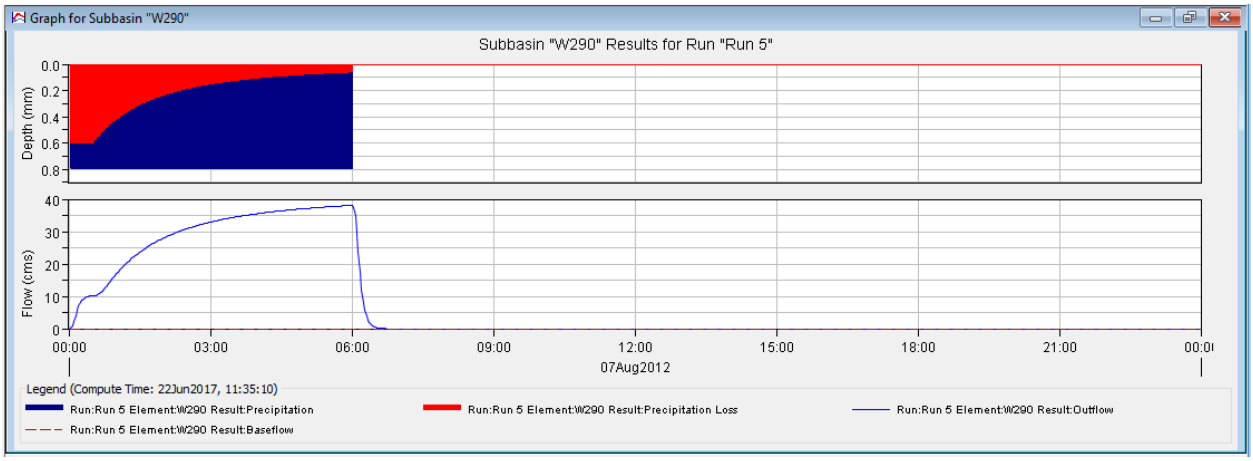


Figure 4.6 b: Sub Basin W290
Source: Authors Analysis (2017)

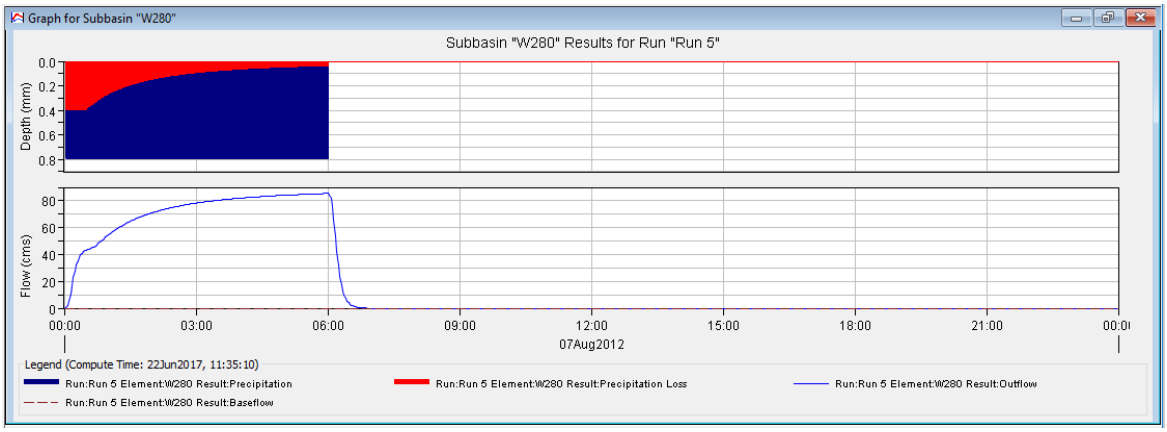


Figure 4.6 c: Sub Basin W280
Source: Authors Analysis (2017)

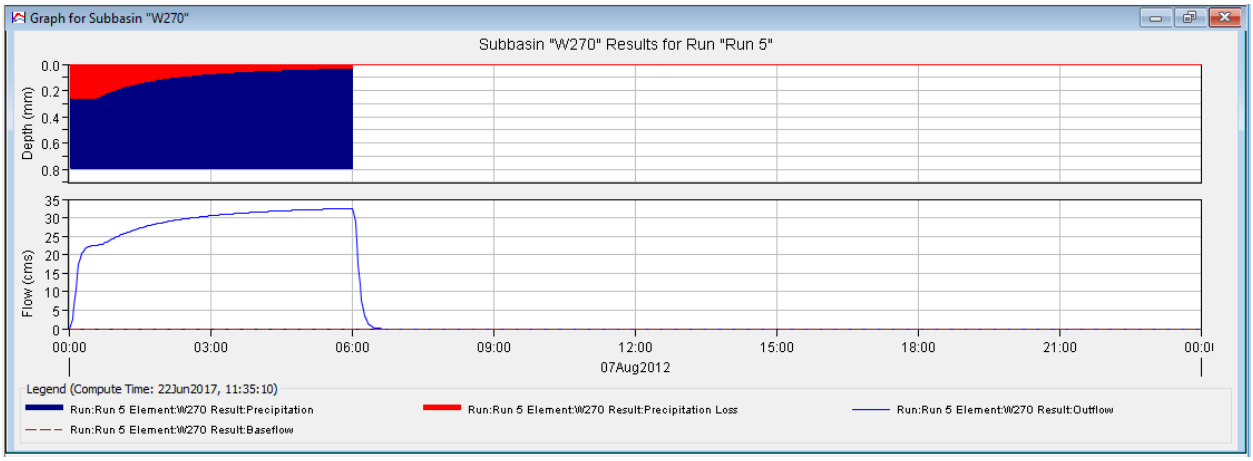


Figure 4.6 d: Sub Basin W270
Source: Authors Analysis (2017)

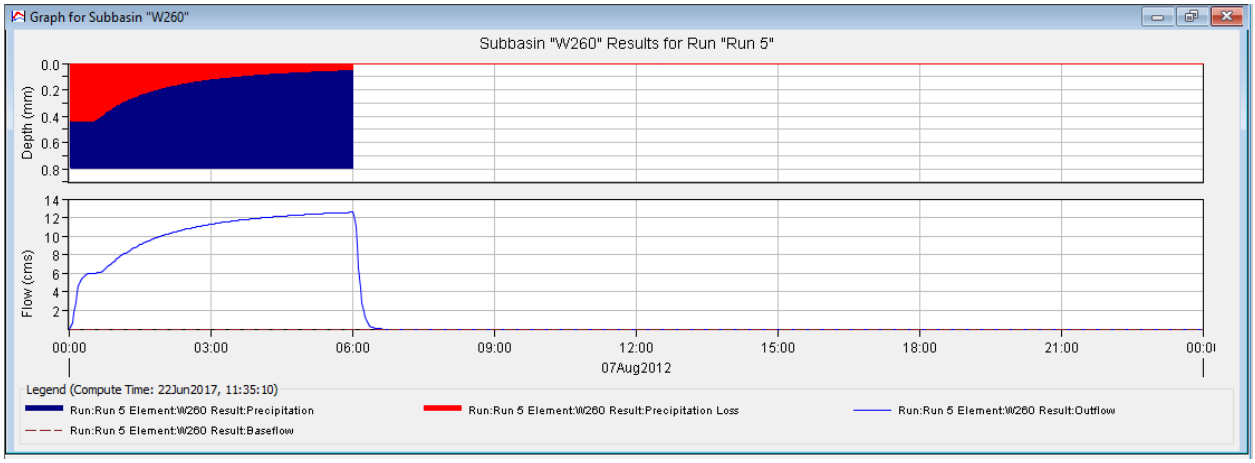


Figure 4.6 e: Sub Basin W260
Source: Authors Analysis (2017)

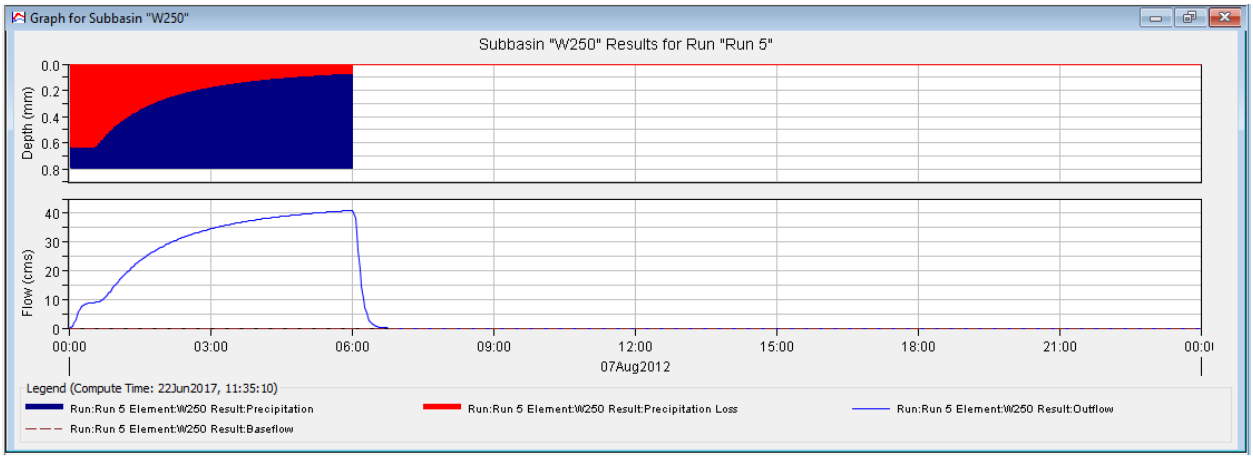


Figure 4.6 f: Sub Basin W250
Source: Authors Analysis (2017)

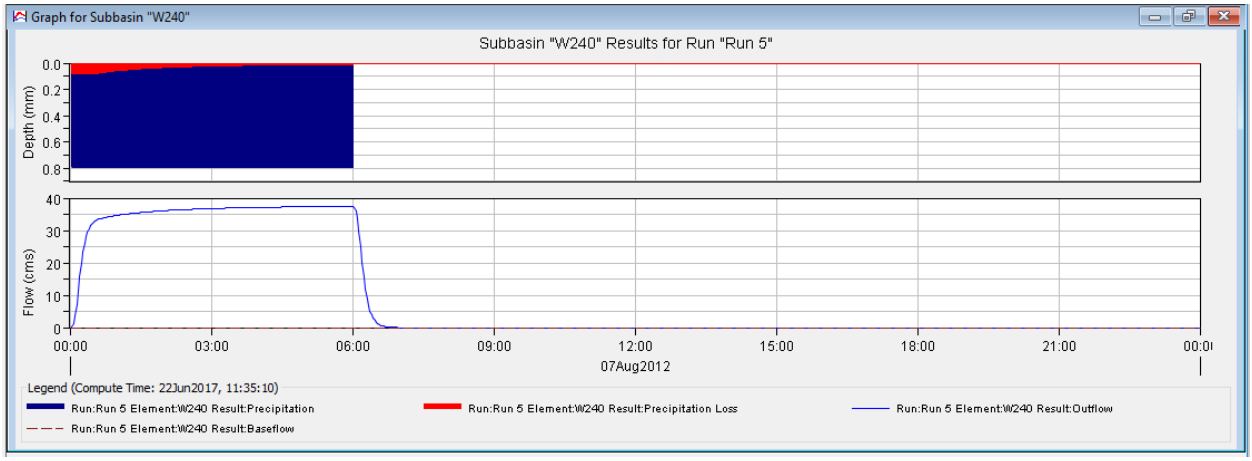


Figure 4.6 g: Sub Basin W240
Source: Authors Analysis (2017)

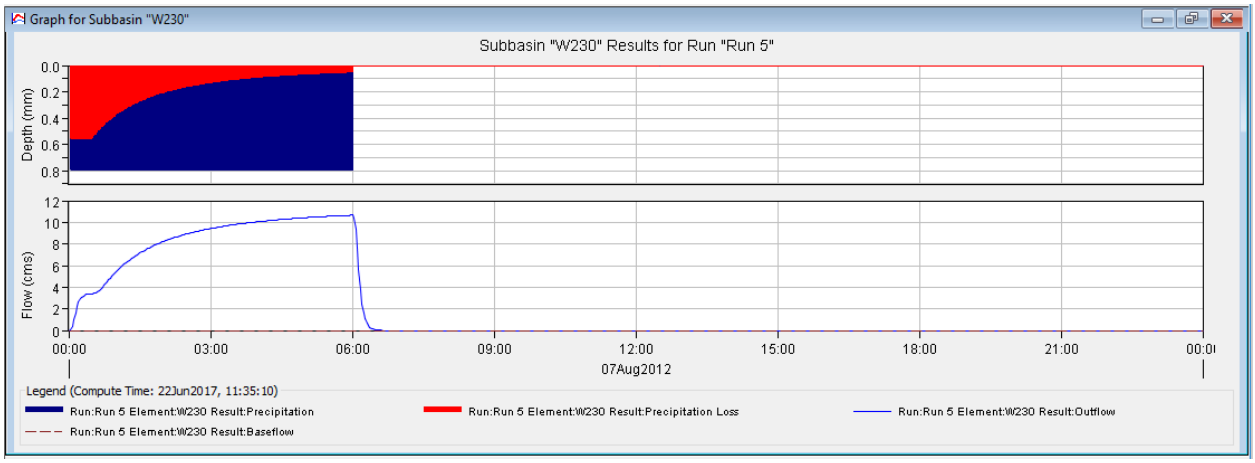


Figure 4.6 h: Sub Basin W230
Source: Authors Analysis (2017)

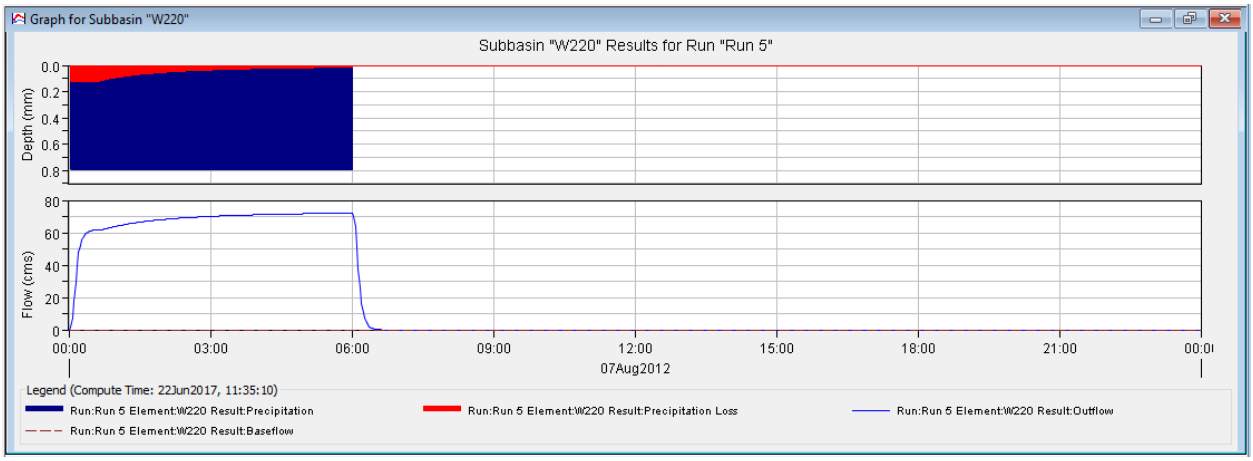


Figure 4.6 i: Sub Basin W220
Source: Authors Analysis (2017)

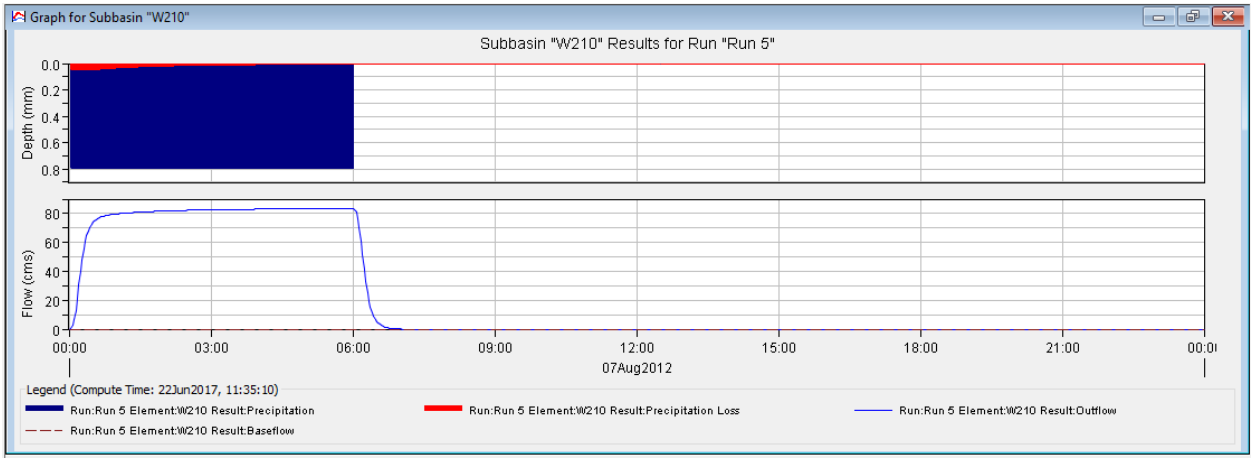


Figure 4.6 j: Sub Basin W210
Source: Authors Analysis (2017)

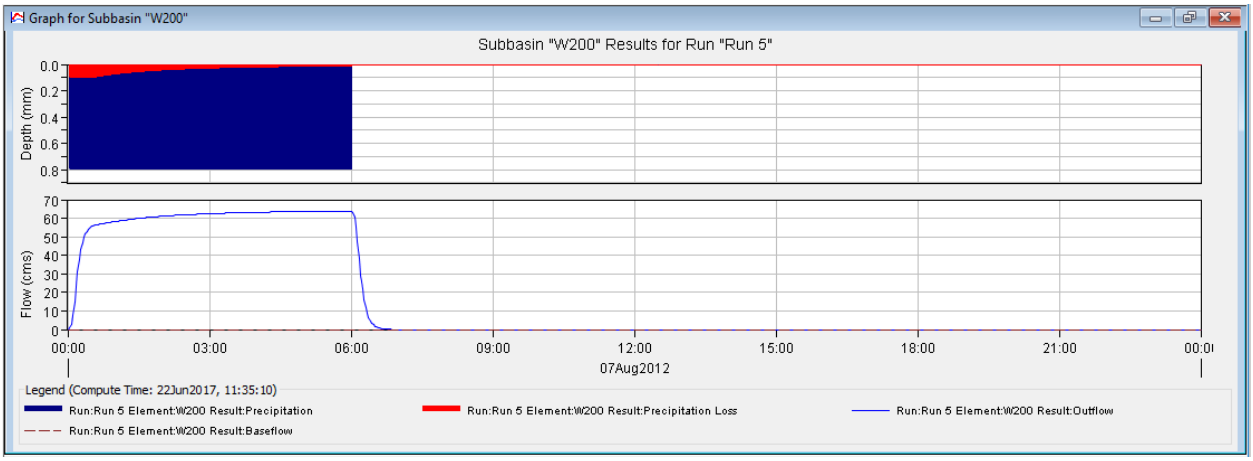


Figure 4.6 k: Sub Basin W200
Source: Authors Analysis (2017)

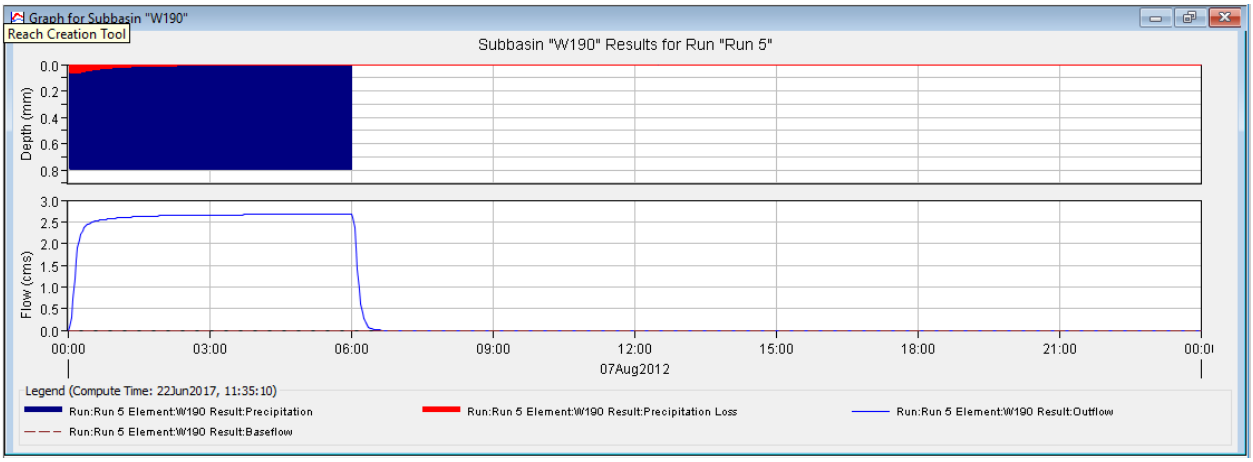


Figure 4.6 l: Sub Basin W190
Source: Authors Analysis (2017)

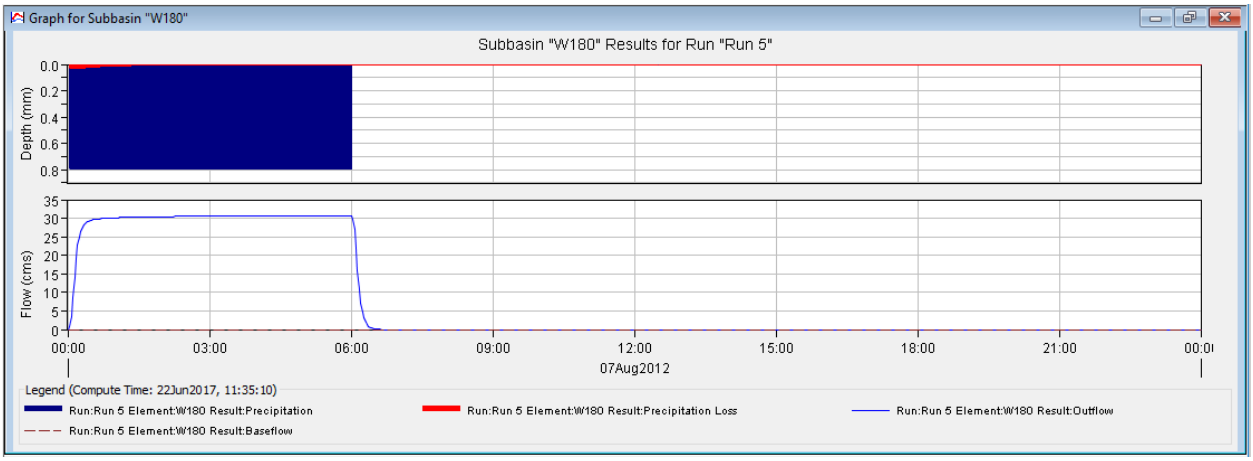


Figure 4.6 m: Sub Basin W180
Source: Authors Analysis (2017)

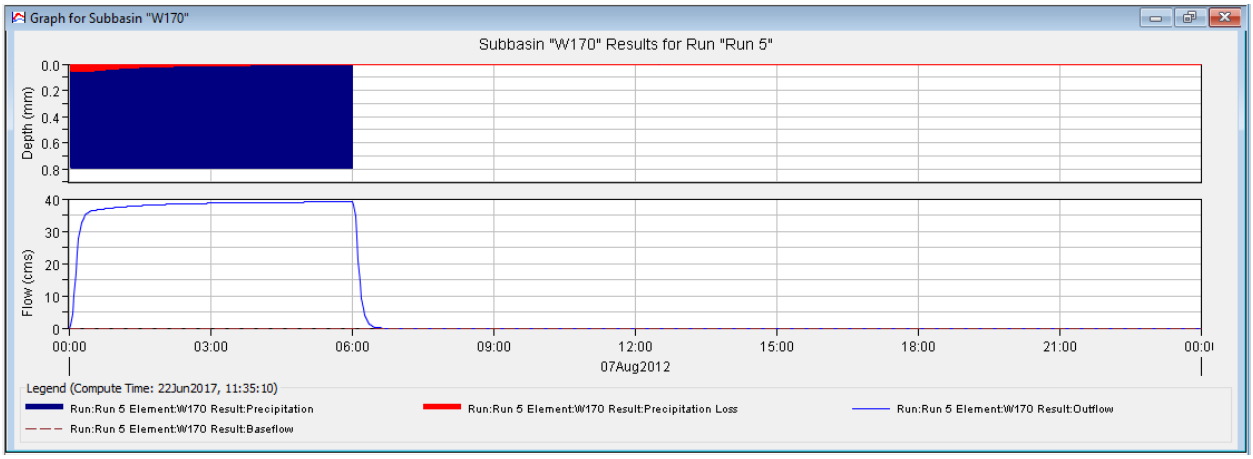


Figure 4.6 n: Sub Basin W170
Source: Authors Analysis (2017)

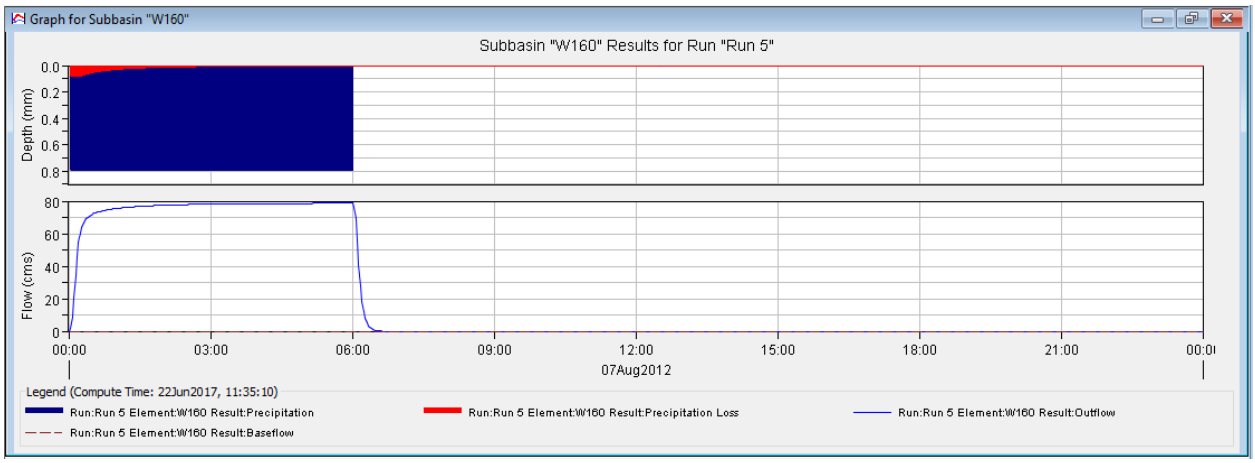


Figure 4.6 o: Sub Basin W160
Source: Authors Analysis (2017)

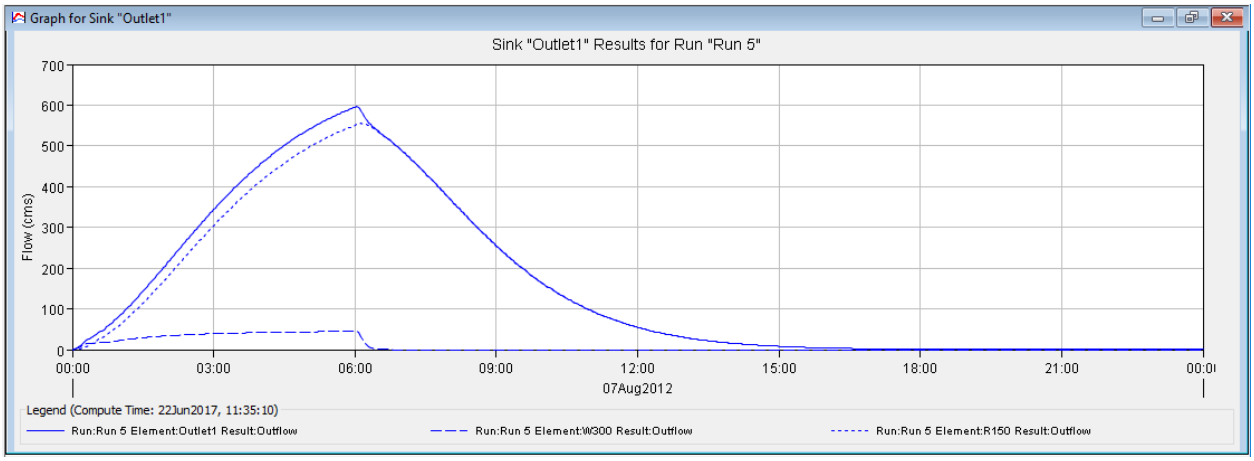


Figure 4.6 p: Outlet Sink
Source: Authors Analysis (2017)

The findings coincide with that of Alghamand *et.al*(2010) where changes in land use land cover increased the peak discharge of run- off. Generally, the outlet of the basin discharged 600cm^3/sec which is much higher than that of 2001 even though with less rainfall amount (143cm^3) indicates a 47% increase in run-off and thus more flood waters.

4.3.6 Chalawa Run off Discharge Simulation 2035 Forecast

The Chalawa basin shows a slight decline in peak discharge of the outlet in 2035(from 600 to 539.7 cm^3/sec) due to considerations of the ongoing canalization of the kwarin Gogaw, Kwanar Madobi and Sabuwar Gandu. This is believed to reduce the amount of discharge within the basin and channel it to a more accommodating stream. The increase in peak discharge was observed in sub-basin W220 and W200 (72cm^3/sec and 64cm^3/sec) which were much lower in 2012. This is in harmony with the findings of Smith (2012) where canalization of the Wanalta Creek County reduced the run-off discharge. It was also revealed in the study of Johnson (1997) that changes in the infiltration rate through paving increases the run-off proportionally to the amount of

paving. Sub-basins W 270, W240, W190, W180, W170, and W160 had no run-off loss which indicates an almost 98% accumulation of run-off.

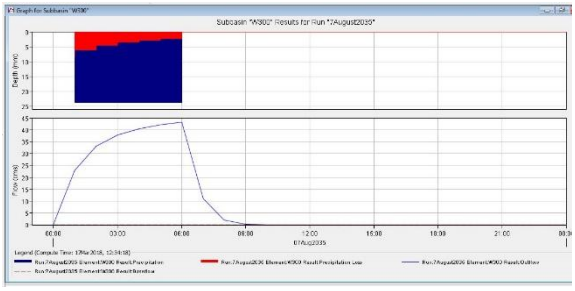


Figure 4.7 a: Sub Basin W300
Source: Authors Analysis (2017)

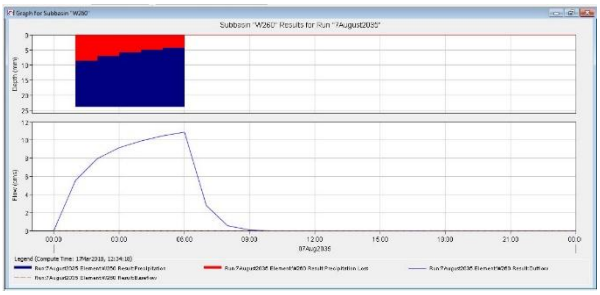


Figure 4.7 e: Sub Basin W260
Source: Authors Analysis (2017)

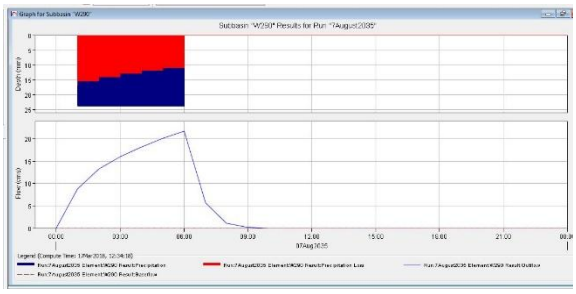


Figure 4.7 b: Sub Basin W290
Source: Authors Analysis (2017)

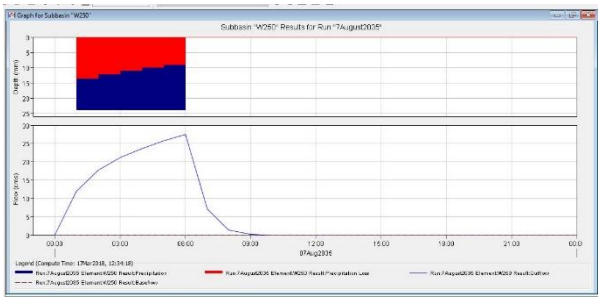


Figure 4.7 f: Sub Basin W250
Source: Authors Analysis (2017)

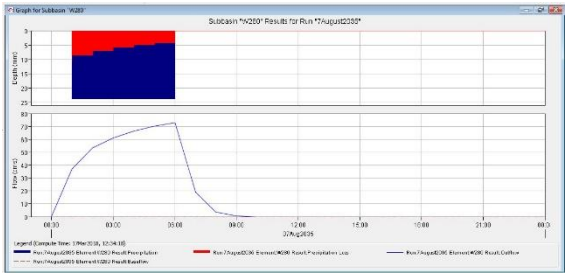


Figure 4.7 c: Sub Basin W280
Source: Authors Analysis (2017)

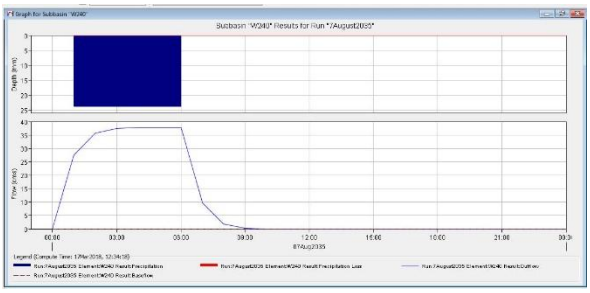


Figure 4.7g: Sub Basin W240
Source: Authors Analysis (2017)

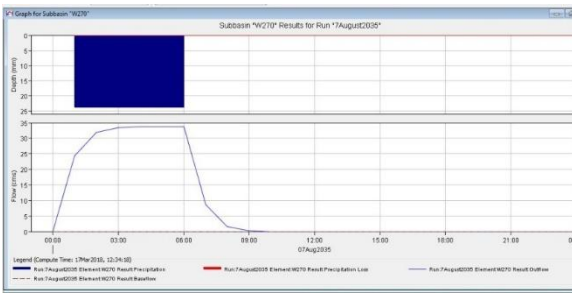


Figure 4.7 d: Sub Basin W270
Source: Authors Analysis (2017)

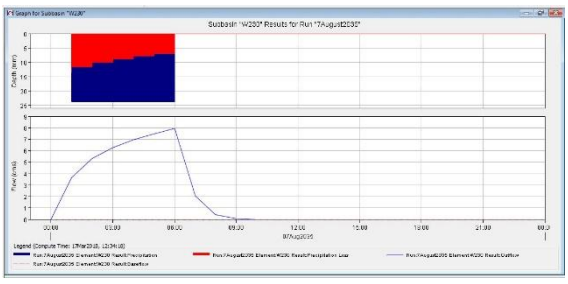


Figure 4.7h: Sub Basin W230
Source: Authors Analysis (2017)

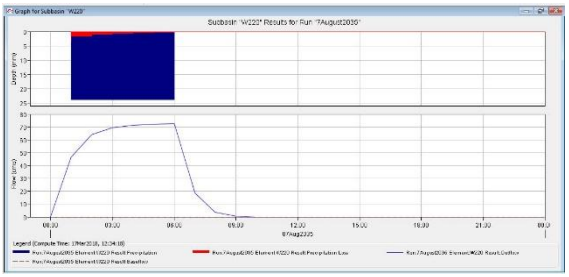


Figure 4.7 i: Sub Basin W220
Source: Authors Analysis (2017)

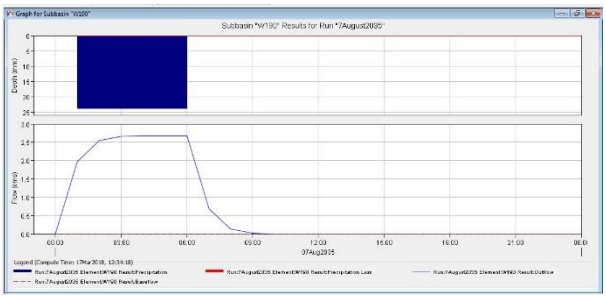


Figure 4.7m: Sub Basin W180
Source: Authors Analysis (2017)

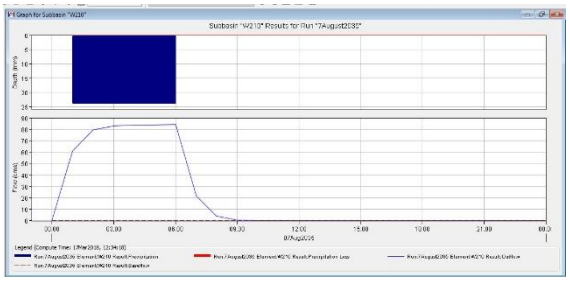


Figure 4.7 j: Sub Basin W210
Source: Authors Analysis (2017)

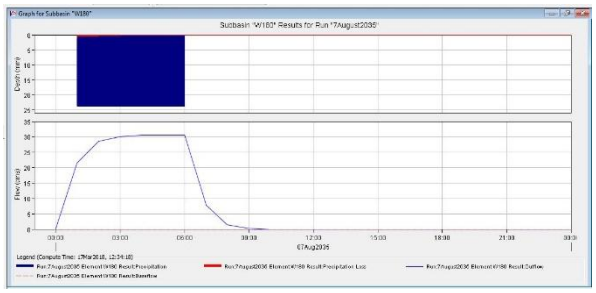


Figure 4.7n: Sub Basin W170
Source: Authors Analysis (2017)

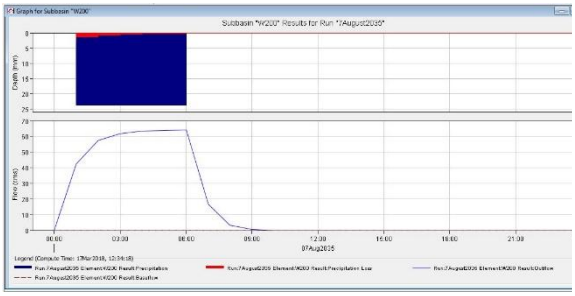


Figure 4.7 k: Sub Basin W200
Source: Authors Analysis (2017)

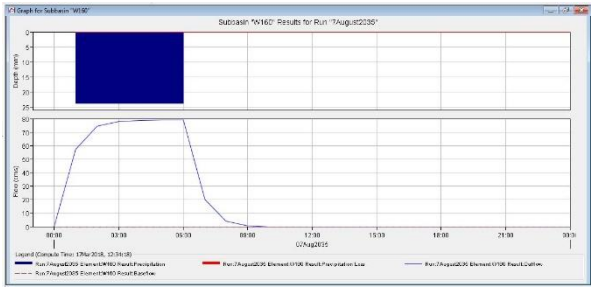


Figure 4.7o: Sub Basin W160
Source: Authors Analysis (2017)

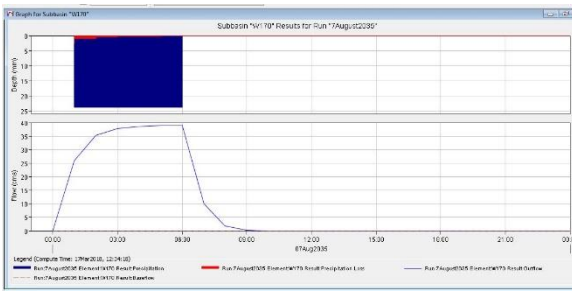


Figure 4.7l: Sub Basin W190
Source: Authors Analysis (2017)

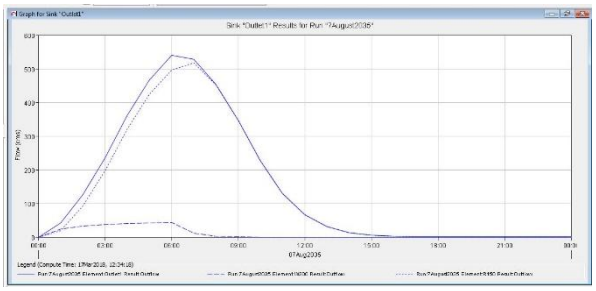


Figure 4.7p: Outlet Sink
Source: Authors Analysis (2017)

Generally, Change in land use and land cover have had a significant impact on the amount of run-off especially in the Chalawa basin in 2012 and the Jakara basin in 2035.These findings are in line with that of Salazar (2012); Thanapura (2011) and Johnson (1997) which revealed that a change in the landscape with impervious surfaces increases the amount of run-off and reduces the time for peak discharge, but the studies of Chu (2009); Sajid (2009); Gupta (2002) and Hernandez (1998) argued that rainfall amount is the most important factor in run-off generation and flooding which this study has revealed to be otherwise.

4.4 FLOOD VULNERABILITY LEVEL IN JAKARA AND CHALAWA BASINS

This section presents the level of vulnerability in the Jakara and Chalawa drainage basins, using the Balica et al. (2012) Flood Vulnerability Index approach (FVI). The analysis is based on the four components which are: Social, Economic, Physical and Environmental vulnerabilities. The computations were done at the sub-basin level.

4.4.1 Jakara Flood Vulnerability index 2001

Table 4.3a, 4.3b, 4.3c, and 4.3d presents the level of social, economic, physical and environmental flood vulnerability in the Jakara basin for 2001 respectively. The interaction between the various indixes of social vulnerability in the Jakara basin in 2001 revealed a high index for most of thesub basins with an index of 0.9,although sub basins W330, W270 and W180 had low indices of 0.3, 0.4 and 0.4 respectively. This is due to high score in the number of persons affected by flooding in the past ten years. Theses sub basins have been mostly affected by flooding in 1988. The indicator PE is part of those that reduces the impact of flooding because it is believed that the more you

are affected by flood occurrences the more resilliance you become through mitigative measures. Likewise, the population growth, child mortality, human development index and communication penetration are virtually the source for all the sub basins. The findings are in agreement Cutter's (2006) framework of vulnerability where an interaction of between low scores of social indicators and high adaptive capacities reduces social vulnerability.

Table 4.3a: Social Flood Vulnerability Index of Jakara Basin in 2001

SUB BASINS	C_H	P_G	H_{DI}	C_M	P_E	A/P	C_{PR}	S	W_S	E_S	FVI
W340	1	2.6	0.43	173.5	120	5	90	2	1	78	0.6
W330	1	2.6	0.43	173.5	400	5	90	0	1	78	0.3
W320	1	2.6	0.43	173.5	0	4	90	3	1	78	0.9
W310	0	2.6	0.43	173.5	0	5	90	2	1	78	0.9
W300	0	2.6	0.43	173.5	112	3	90	3	1	78	0.6
W290	0	2.6	0.43	173.5	38	1	90	4	1	78	0.8
W280	0	2.6	0.43	173.5	0	1	90	0	1	78	0.9
W270	0	2.6	0.43	173.5	280	1	90	3	1	78	0.4
W260	0	2.6	0.43	173.5	0	1	90	0	1	78	0.9
W250	0	2.6	0.43	173.5	0	2	90	2	1	78	0.9
W240	0	2.6	0.43	173.5	0	2	90	5	1	78	0.9
W230	0	2.6	0.43	173.5	18	2	90	0	1	78	0.9
W220	0	2.6	0.43	173.5	212	2	90	3	1	78	0.5
W210	0	2.6	0.43	173.5	0	2	90	0	1	78	0.9
W200	0	2.6	0.43	173.5	15	2	90	3	1	78	0.9
W190	0	2.6	0.43	173.5	216	2	90	4	1	78	0.5
W180	0	2.6	0.43	173.5	309	1	90	0	1	78	0.4

Source: Authors Analysis (2017)

The economic flood vulnerability index had a lower value compared to the social components. The highest index of 0.9 was recorded in sub basin W200 indicating high vulnerability. This is as a result of low investiment in flood mitigation within the basin and the basin comparises of high density and low income unplanned settlements. The lowest indicies were recorded in sub basins W330, W310, and W270 with 0.4 each indicating moderate vulnerability to floods (see Table 4.3b). These basins are more organized and with better investment in flood mitigation. This agrees with the third approach of the spheres of vulnerability by Birkmann (2005) where level of vulnerability is as a result of the interaction between systems susceptibility to external harm and its coping capacity, in this study the amount of investment in flood mitigation is more towards flood mitigation which drastically reduced flood vulnerability.

The physical component had very low index values due to low slope gradient especially for sub basin W300 and W260 but with the exception of W190 which has a steep gradient and an index score of 0.7 indicating high vulnerability. The drainage system is also well established in sub basins W300 and W290, thereby having the ability to reduce the impact of flood waters. These findings further show the importance of canalization and slope gradient on the impacts off flood vulnerability and occurrrences also reported by Aderogba (2012).

Sub basins W200, W190 and W180 had the highest environmental vulnerability with an index score of 0.8 each, while sub basins W330 and W280 had the lowest index score of 0.3 which is also considerably high according to the Balica (2012) scale. The findings of Vlachos (2010) had much lower values were recorded for basins with fewer land uses and better resilliance indices within the study area. Furthermore, studies hy Yahaya and Abdallah (2010) also confirmed the findings of this study but with fewer details.

Table 4.3 b: Economic Flood Vulnerability Index of Jakara Basin in 2001

SUB BASINS	I_{ND}	U_G	R_T	F_I	AM_{INV}	FVI
W340	40	20	3	1	98	0.6
W330	28	20	3	1	109	0.4
W320	22	20	3	1	82	0.5
W310	5	20	3	1	69	0.4
W300	0	20	3	1	42	0.5
W290	0	20	3	1	31	0.7
W280	0	20	3	1	32	0.7
W270	3	20	3	1	63	0.4
W260	2	20	3	1	38	0.7
W250	0	20	3	1	38	0.6
W240	0	20	3	1	49	0.5
W230	0	20	3	1	39	0.6
W220	2	20	3	1	37	0.7
W210	3	20	3	1	46	0.6
W200	0	20	3	1	26	0.9
W190	0	20	3	1	41	0.5
W180	0	20	3	1	32	0.7

Source: Authors Analysis (2017)

The economic flood vulnerability index had a lower value compared to the social component, which indicated high vulnerability to flood for five of the sub-basins which are mostly situated in the highly urbanized areas of the basin. The physical component had very low values due to the low slope gradient especially for sub-basins W300 and W260, but with the exception of W190 which have a steep gradient and a score of 0.7 indicating high vulnerability.

Table 4.3c: Physical Flood Vulnerability Index of Jakara Basin in 2001

SUB BASINS	T	D	FVI
W340	482	1336	0.3
W330	486	1929	0.2
W320	471	1391	0.3
W310	482	2245	0.2
W300	463	5195	0.1
W290	480	1800	0.2
W280	472	3080	0.2
W270	462	1725	0.3
W260	446	5195	0.1
W250	462	2590	0.2
W240	473	1298	0.4
W230	460	1521	0.3
W220	448	1020	0.5
W210	485	1800	0.3
W200	468	1113	0.4
W190	443	593	0.7
W180	481	1707	0.2

Source: Authors Analysis (2017)

Environmental flood vulnerability index of sub-basins W200, 190 and W180 had the highest environmental vulnerability with a score of 0.8 while W330 and 280 had the lowest score of 0.3 which is considerably high according to the Balica (2013) flood vulnerability index table. The findings are in disagreement that of Vlachos (2010) where much lower values were recorded as a result of better resilience indices within the study area. Furthermore studies by Yahaya et.al. (2010) also confirmed this findings, but with less details.

Table 4.3d: Environmental Flood Vulnerability Index of Jakara in 2001

SUB BASINS	U_G	L_U	FVI
W340	20	50	0.4
W330	20	60	0.3
W320	20	30	0.6
W310	20	40	0.5
W300	20	35	0.6
W290	20	31	0.6
W280	20	60	0.3
W270	20	42	0.5
W260	20	31	0.6
W250	20	28	0.7
W240	20	41	0.5
W230	20	33	0.6
W220	20	28	0.7
W210	20	31	0.6
W200	20	25	0.8
W190	20	24	0.8
W180	20	25	0.8

Source: Authors Analysis (2017)

4.3.2 Jakara Flood Vulnerability index 2012

Table 4.3e, 4.3f, 4.3g, and 4.3h present the level of flood vulnerability in the Jakara basin for 2012.

Table 4.3e: Social Flood Vulnerability Index of Jakara Basin in 2012

SUB BASIN	CH	HDI	PG	CM	PE	A/P	CPR	S	WS	ES	FVI
W340	1	0.53	2.6	183	192	6	90	2	1	132	0.4
W330	1	0.53	2.6	102	420	6	90	0	1	132	0.2
W320	1	0.53	2.6	32	17	4	90	3	1	132	0.1
W310	0	0.53	2.6	28	22	5	90	2	1	132	0.1
W300	0	0.53	2.6	115	133	2	90	3	1	132	0.3
W290	0	0.53	2.6	52	49	1	90	4	1	132	0.2
W280	0	0.53	2.6	84	340	1	90	0	1	132	0.2
W270	0	0.53	2.6	174	310	1	90	3	1	132	0.3
W260	0	0.53	2.6	48	0	1	90	0	1	132	0.2
W250	0	0.53	2.6	16	0	3	90	3	1	132	0.1
W240	0	0.53	2.6	18	0	1	90	6	1	132	0.1
W230	0	0.53	2.6	10	18	2	90	0	1	132	0.1
W220	0	0.53	2.6	210	212	2	90	3	1	132	0.5
W210	0	0.53	2.6	121	0	2	90	0	1	132	0.6
W200	0	0.53	2.6	17	32	3	90	3	1	132	0.1
W190	0	0.53	2.6	184	216	2	90	4	1	132	0.4
W180	0	0.53	2.6	67	309	1	90	0	1	132	0.1

Source: Authors Analysis (2017)

The social flood vulnerability index of the Jakara basin in 2012 shows decline compared to 2001 in most of the sub basins. Sub basins W210 had the highest index score of 0.6 which indicate high vulnerability most of the score of the other sub basins chope as a results of a rise in HDI, specific CM figures for each sub basin and an increase in the number of frequency service workers. The result revealed an increase in resilliance by individual sub basins reduces the level of vulnerability to flood. The fourth sphere of vulnerability by Birkmann (2005) further affirms these findings.

Table 4.3f: Economic Flood Vulnerability Index of Jakara Basin in 2012

SUB BASINS	I_{ND}	U_G	R_T	F_I	AM_{INV}	FVI
W340	42	34	3	1	242	0.3
W330	29	34	3	1	187	0.4
W320	18	34	3	1	119	0.5
W310	3	34	3	1	96	0.4
W300	0	34	3	1	61	0.6
W290	2	34	3	1	48	0.8
W280	1	34	3	1	42	0.9
W270	3	34	3	1	69	0.6
W260	4	34	3	1	40	0.9
W250	2	34	3	1	42	0.9
W240	1	34	3	1	48	0.8
W230	2	34	3	1	40	0.9
W220	2	34	3	1	52	0.7
W210	4	34	3	1	55	0.7
W200	2	34	3	1	63	0.6
W190	3	34	3	1	47	0.8
W180	1	34	3	1	62	0.6

Source: Authors Analysis (2017)

The economic flood vulnerability index rrevealed a different pattern from that of 2001 with an increase the number of sub basins W280, W260, W250 and W230 have scores of 0.9 which indicates very high vulnerability and sub basins W340 recorded the lowest with 0.3 which is also moderately high. The increase was as a result of the rise in urban growth. This finding is in agreement with the results of Nabegu (2014) where difference in coping mechanisms can determine the lelvel of vulnerability.

Table 4.3 g: Physical Flood Vulnerability Index of Jakara Basin in 2012

SUB BASINS	T	D	FVI
W340	482	1336	0.3
W330	486	1929	0.2
W320	471	1391	0.3
W310	482	2245	0.2
W300	463	5195	0.1
W290	480	1800	0.2
W280	472	3080	0.2
W270	462	1725	0.3
W260	446	5195	0.1
W250	462	2590	0.2
W240	473	1298	0.4
W230	460	1521	0.3
W220	448	1020	0.5
W210	485	1800	0.3
W200	468	1113	0.4
W190	443	593	0.7
W180	481	1707	0.2

Source: Authors Analysis (2017)

The physical component had very low index values due to low slope gradient especially for sub basin W300 and W260 but with the exception of W190 which has a steep gradient and an index score of 0.7 indicating high vulnerability. The drainage system is also well established in sub basins W300 and W290, thereby having the ability to reduce the impact of flood waters. These findings further show the importance of canalization and slope gradient on the impacts off flood vulnerability and occurrrences also reported by Aderogba (2012).

Table 4.3 h: Environmental Flood Vulnerability Index of Jakara Basin in 2012

	U_G	L_U	FVI
W340	34	58	0.6
W330	34	63	0.5
W320	34	38	0.9
W310	34	42	0.8
W300	34	43	0.8
W290	34	39	0.9
W280	34	72	0.5
W270	34	49	0.7
W260	34	48	0.7
W250	34	39	0.9
W240	34	52	0.7
W230	34	47	0.7
W220	34	38	0.9
W210	34	52	0.7
W200	34	48	0.7
W190	34	50	0.7
W180	34	52	0.7

Source: Authors Analysis (2017)

The environmental FVI resembles the pattern of the economic FVI where rise in vulnerability occurs in sub basins W320 and W290 from 0.6 in 2001 to 0.9 in 2012 which indicates very high vulnerability. This riise in vulnerability is attributed to an increase in urban growth and significance change in landuse from pervious surfaces to impervious surfaces (see Figure 4.1b). this is supported by (Moris-Osald and Sinclair, 2005; Barroca et.al, 2006) which states that change in built up surfaces results in a rise in peak discharge, increase in flooding and eventually increasing flood vulnerability.

The Social Flood vulnerability index of the Jakara basin in 2012 shows a decline in most of the sub-basins as a result of a rise in human development index and number ofemergency services workers and a drop in child mortality rate (Table 4.3e). The highest score was 0.6 and the lowest 0.5; this still indicates high social flood vulnerability for 2012. The economic flood vulnerability index revealed a different

pattern from the social FVI with an increase in vulnerability of sub basin W280 and W260 from 0.7 to 0.9 (Table 4.3f). This is attributed to the increase in urban growth, peak discharge and also supported by the findings of Balica and Wright (2010) which reveals that an increase score of any indicator that supports resilience reduces the level of vulnerability. The environmental FVI resembles the pattern of the economic FVI, where a rise in vulnerability occurs in sub-basin W320 and W290 with 0.9, making the basin very vulnerable to floods. The increase in Vulnerability follows the same pattern of built up area (Figure 4.1b) and a rise in peak discharge within the Jakara basin in 2012. This is supported by the work of (Moris-Osald and Sinclair, 2005; Barroca *et.al.* 2006) which states that a change in built up cover results in a rise in peak discharge which eventually increases vulnerability.

4.4.2 Jakara Flood Vulnerability index 2035

Table 4.3i, 4.3j, 4.3k, and 4.3l present the level of flood vulnerability in the Jakara basin for 2035.

The social vulnerability of the Jakara basin in 2035 saw a general decline in the entire basin as compared to 2001 and 2012. The vulnerability level 0.1 as a result of a drop in child mortality rate and increase in human development indices and also an increase in the number of emergency service workers within the basin. These findings agree with Balica et.al (2009) and Barroka et.al (2006) where increase in such indicators reduces flood vulnerability.

Table 4.3 i: Social Flood Vulnerability Index of Jakara Basin in 2035

SUB BASINS	H_{DI}	C_H	P_G	C_M	P_E	A/P	C_{PR}	S	W_S	E_S	FVI
W340	0.63	1	2.6	51.3	0	4	90	4	1	200	0.2
W330	0.63	1	2.6	51.3	19	4	90	2	1	200	0.2
W320	0.63	1	2.6	51.3	0	3	90	5	1	200	0.2
W310	0.63	0	2.6	51.3	0	4	90	2	1	200	0.2
W300	0.63	0	2.6	51.3	121	1	90	5	1	200	0.1
W290	0.63	0	2.6	51.3	128	0	90	6	1	200	0.1
W280	0.63	0	2.6	51.3	58	3	90	2	1	200	0.2
W270	0.63	0	2.6	51.3	0	3	90	5	1	200	0.2
W260	0.63	0	2.6	51.3	0	1	90	2	1	200	0.2
W250	0.63	0	2.6	51.3	0	1	90	5	1	200	0.2
W240	0.63	0	2.6	51.3	0	3	90	7	1	200	0.2
W230	0.63	0	2.6	51.3	0	2	90	2	1	200	0.2
W220	0.63	0	2.6	51.3	0	1	90	5	1	200	0.2
W210	0.63	0	2.6	51.3	0	1	90	2	1	200	0.2
W200	0.63	0	2.6	51.3	0	1	90	5	1	200	0.2
W190	0.63	0	2.6	51.3	0	1	90	6	1	200	0.2
W180	0.63	0	2.6	51.3	0	1	90	2	1	200	0.2

Source: Authors Analysis (2017)

The economic FVI also compounded to 2012 results. The highest score fro 2012 was 0.9 indicating very high vulnerability while that of 2035 is 0.5 indicating moderate vulnerability. The decrease in vulnerability is attributed in a rise in the adaptive indicators such as amount of investment in flood mitigation and time taken for the metropolis to recover after flood events. This agrees with the considerations by Brooks

(2003) and Robert et.al (2009) where context-specific approaches consider the importance of individual indicators in reducing or increasing vulnerability.

Table 4.3 j: Economic Flood Vulnerability Index of Jakara in 2035

	I_{ND}	U_G	R_T	F_I	AM_{INV}	FVI
W340	52	54.4	2	1	342	0.3
W330	39	54.4	2	1	287	0.3
W320	28	54.4	2	1	219	0.4
W310	13	54.4	2	1	196	0.4
W300	10	54.4	2	1	161	0.4
W290	12	54.4	2	1	148	0.5
W280	11	54.4	2	1	142	0.5
W270	13	54.4	2	1	169	0.4
W260	14	54.4	2	1	140	0.5
W250	20	54.4	2	1	142	0.5
W240	11	54.4	2	1	148	0.5
W230	12	54.4	2	1	140	0.5
W220	12	54.4	2	1	152	0.4
W210	14	54.4	2	1	155	0.5
W200	12	54.4	2	1	163	0.4
W190	13	54.4	2	1	147	0.5
W180	11	54.4	2	1	162	0.4

Source: Authors Analysis (2017)

The physical component had very low index values due to low slope gradient especially for sub basin W300 and W260 but with the exception of W190 which has a steep gradient and an index score of 0.7 indicating high vulnerability. The drainage system is also well established in sub basins W300 and W290, thereby having the ability to reduce the impact of flood waters. These findings further show the importance of canalization

and slope gradient on the impacts off flood vulnerability and occurrrences also reported by Aderogba (2012).

Table 4.3 k: Physical Flood Vulnerability Index of Jakara Basin in 2035

SUB BASINS	T	D	FVI
W340	482	1336	0.3
W330	486	1929	0.2
W320	471	1391	0.3
W310	482	2245	0.2
W300	463	5195	0.1
W290	480	1800	0.2
W280	472	3080	0.2
W270	462	1725	0.3
W260	446	5195	0.1
W250	462	2590	0.2
W240	473	1298	0.4
W230	460	1521	0.3
W220	448	1020	0.5
W210	485	1800	0.3
W200	468	1113	0.4

Source: Authors Analysis (2017)

The environmental FVI maintains its high scores with sub basins W230, W190 and W180 which recording very high vulnerability to flood with 0.9. A study by Baarse (1995)substantiated the impact of urban growth on flood vulnerability. Most of these areas within the sub basins are usually high density, low income and unplanned areas such as Dorayi, sabuwar madina and Salata which makes them highly vulnerable.

Table 4.3 l: Environmental Flood Vulnerability Index of Jakara Basin in 2035

SUB BASINS	UG	LU	FVI
W340	54.4	94	0.6
W330	54.4	93	0.6
W320	54.4	94	0.6
W310	54.4	90	0.6
W300	54.4	87	0.6
W290	54.4	72	0.8
W280	54.4	70	0.8
W270	54.4	68	0.8
W260	54.4	69	0.8
W250	54.4	70	0.8
W240	54.4	74	0.7
W230	54.4	62	0.9
W220	54.4	66	0.8
W210	54.4	71	0.8
W200	54.4	68	0.8
W190	54.4	61	0.9
W180	54.4	63	0.9

Source: Authors Analysis (2017)

The Social Flood Vulnerability of Jakara basin in 2035 saw a general decline in the entire basin to low vulnerability (0.1) this is attributed to a better human development index, an increase in emergency services workers and a further drop in child mortality rate. This agrees with Balica and Wright (2010) and Barroca *et.al* (2006) where an increase in such indicators reduces flood vulnerability. The economic FVI also dropped from 0.9 to 0.5 and this indicates a lower vulnerability according to the Balica *et al*. (2009) FVI scale. The Environmental FVI maintains its high score with sub-basins W230, W190 and W180 Recording the highest vulnerability. A study by Baarse (1995) substantiated the impact of urban growth on flood vulnerability.

4.4.3 Chalawa Flood Vulnerability Index 2001

Table 4.3m, 4.3n, 4.3o, and 4.3p present the level of flood vulnerability in the Jakara basin for 2001.

Table 4.3 m: Social Flood Vulnerability Index of Chalawa in 2001

SUB BASINS	HDI	CH	PG	CM	PE	A/P	CPR	S	WS	ES	FVI
W300	0.43	0	2.6	181.7	82	3	90	1	1	78	0.7
W290	0.43	0	2.6	181.7	72	3	90	1	1	78	0.8
W280	0.43	0	2.6	181.7	68	4	90	1	1	78	0.8
W270	0.43	0	2.6	181.7	79	3	90	1	1	78	0.7
W260	0.43	0	2.6	181.7	93	5	90	1	1	78	0.7
W250	0.43	1	2.6	181.7	65	5	90	1	1	78	0.8
W240	0.43	1	2.6	181.7	83	5	90	1	1	78	0.7
W230	0.43	1	2.6	181.7	77	4	90	0	1	78	0.7
W220	0.43	2	2.6	181.7	120	4	90	0	1	78	0.6
W210	0.43	1	2.6	181.7	210	5	90	0	1	78	0.5
W200	0.43	3	2.6	181.7	240	6	90	3	1	78	0.4
W190	0.43	2	2.6	181.7	218	6	90	4	1	78	0.5
W180	0.43	2	2.6	181.7	271	6	90	5	1	78	0.4
W170	0.43	2	2.6	181.7	252	6	90	6	1	78	0.4
W160	0.43	2	2.6	181.7	117	6	90	5	1	78	0.6

The social vulnerability index in Chalawa basin in 2001 resembles that of Jakara basin. Sub basins W290, W280 and W250 have very high vulnerability while W200, W180 and W170 had the lowest score of 0.4 but indicating moderate vulnerability generally the basin has a very high social vulnerability due to high child mortality, lack of warning system, and inadequate emergency shelters and hospitals. These indicators inceases the resilliance and coping capacity to flood events and hence the reason for very Turner

et.al, 2003 confirmed this findings and further restricted the inportances resilience indicators to flood vulnerability reduction.

Table 4.3 n: Economic Flood Vulnerability Index of Chalawa Basin in 2001

SUB BASINS	IND	UG	RT	FI	AMINV	FVI
W300	23	20	3	1	230	0.2
W290	8	20	3	1	80	0.4
W280	14	20	3	1	140	0.3
W270	12	20	3	1	120	0.3
W260	7	20	3	1	70	0.4
W250	2	20	3	1	30	0.8
W240	3	20	3	1	30	0.8
W230	2	20	3	1	30	0.8
W220	6	20	3	1	60	0.5
W210	8	20	3	1	80	0.4
W200	4	20	3	1	40	0.7
W190	2	20	3	1	30	0.8
W180	2	20	3	1	30	0.8
W170	3	20	3	1	30	0.8
W160	2	20	3	1	30	0.8

Source: Authors Analysis (2017)

The economic flood vulnerability index for Chalawa basin in 2001 is generally very high with seven (7) sub basins recording a score of 0.8. The reason for this is the amount of investment in flood mitigation is low and there is no flood insurance. The index is much higher than that of Jakara in the same year. This findings also agrees with Birkmann (2005) flood vulnerability framework.

The physical vulnerability index of the Chalawa basin in 2001 resembles that of the Jakara basin of the same year but with a little difference. Sub basin W190 had the highest index indicating very high vulnerability and the lowest index was 0.2for five (5) sub basin W190 has less drainage network computed to those lower indices and hence, has less competence to Chalawa runoff. A study by smith (2012) agrees with

thesefindings through highlighting the importance of drainage network in reducing flood occurrences and thereby lowering flood vulnerability.

Table 4.3 o: Physical Flood Vulnerability Index of Chalawa Basin in 2001

SUB BASINS	T	D	FVI
W300	456.5	18185	0.03
W290	476.8	15030	0.03
W280	464.6	23381	0.02
W270	457.7	14103	0.03
W260	468.8	9278	0.05
W250	482.9	16886	0.03
W240	471.9	17072	0.03
W230	464	9278	0.05
W220	481	19670	0.02
W210	477.4	23381	0.02
W200	471	20041	0.02
W190	472.6	5010	0.09
W180	483.8	15958	0.03
W170	481	14288	0.03
W160	484	20969	0.02

Source: Authors Analysis (2017)

Sub basins W300 and W200 had the highest flood vulnerability index in the Chalawa basin in 2001 while sub basins W210, W180 and W170 had scores of 0.3 which indicates moderate vulnerability. Theses sub basins are situated in areas that are within the outskirts of pervious layers. Studies by Weichesetgartner (2000) and Cutter (1996) have emphasized the relevance of physical environmental condition in reducing or increasing flood vulnerability.

Table 4.3 p: Environmental Flood Vulnerability Index of Chalawa Basin in 2001

SUB BASINS	U_G	L_U	FVI
W300	20	30	0.7
W290	20	32	0.6
W280	20	38	0.5
W270	20	52	0.4
W260	20	48	0.4
W250	20	33	0.6
W240	20	37	0.5
W230	20	41	0.5
W220	20	32	0.6
W210	20	68	0.3
W200	20	28	0.7
W190	20	55	0.4
W180	20	75	0.3
W170	20	66	0.3
W160	20	40	0.5

Source: Authors Analysis (2017)

4.4.4 Chalawa Flood Vulnerability Index 2012

Table 4.3q, 4.3r, 4.3s, and 4.3t present the level of flood vulnerability in the Jakara basin for 2012.

Genrally the social vulnerability in the Chalawa basin in 2012 is high, with indices ranging between 0.5 and 0.6 on Balica scale. The outcome in Chalawa has been much higher than that of the Jakara basin in 2012. The reason is mainly because the emergency service worker and fewer, child mortality rate constant, awareness and preparedness is also low and hence this high vulnerability. The findings agrees with that

of Cutter and Finch (2008) which revealed the importance lowering the susceptibility and exposure of community and its effect on vulnerability level.

Table 4.3 q: Social Flood Vulnerability Index of Chalawa Basin in 2012

	C_H	H_{DI}	P_G	C_M	P_E	A/P	C_{PR}	S	W_S	E_S	FVI
W300	0	0.53	2.6	120	0	2	90	1	1	112	0.6
W290	0	0.53	2.6	120	0	2	90	1	1	112	0.6
W280	0	0.53	2.6	120	0	2	90	1	1	112	0.6
W270	0	0.53	2.6	120	0	2	90	1	1	112	0.6
W260	0	0.53	2.6	120	0	2	90	1	1	112	0.6
W250	0	0.53	2.6	120	0	2	90	1	1	112	0.6
W240	1	0.53	2.6	120	0	5	90	1	1	112	0.6
W230	1	0.53	2.6	120	0	5	90	1	1	112	0.6
W220	1	0.53	2.6	120	18	2	90	3	1	112	0.5
W210	1	0.53	2.6	120	27	2	90	4	1	112	0.5
W200	0	0.53	2.6	120	14	2	90	3	1	112	0.6
W190	1	0.53	2.6	120	12	2	90	3	1	112	0.6
W180	3	0.53	2.6	120	48	6	90	4	1	112	0.5
W170	2	0.53	2.6	120	42	5	90	4	1	112	0.5
W160	2	0.53	2.6	120	32	5	90	3	1	112	0.5

Source: Authors Analysis (2017)

Sub basins W300 and W280 had vulnerability of 0.3 indicating moderate vulnerability of floods, these basins are situated within the Kumbotso area which have more of open spaces, lower population density and more investment in flood mitigation compared to sub basins W230 and W200 which are located within Gwale Local Govrnemnt Area. This area is highly unplanned, density populated and with less investment in flood

mitigation s a vital components of resilliance to flood as stated by Birkmann (2006a) and hence the reason for the present findings.

Table 4.3 r: Economic Flood Vulnerability Index of Chalawa Basin in 2012

SUB BASINS	IND	UG	RT	FI	AMINV	FVI
W300	24	34.3	3	1	240	0.3
W290	9	34.3	3	1	90	0.5
W280	16	34.3	3	1	160	0.3
W270	14	34.3	3	1	140	0.4
W260	13	34.3	3	1	130	0.4
W250	11	34.3	3	1	100	0.5
W240	10	34.3	3	1	95	0.5
W230	2	34.3	3	1	50	0.8
W220	6	34.3	3	1	60	0.7
W210	7	34.3	3	1	70	0.6
W200	3	34.3	3	1	52	0.8
W190	6	34.3	3	1	60	0.7
W180	6	34.3	3	1	60	0.7
W170	4	34.3	3	1	56	0.7
W160	6	34.3	3	1	60	0.7

Source: Authors Analysis (2017)

The physical vulnerability index of the Chalawa basin in 2012 resembles that of the Jakara basin of the same year but with a little difference. Sub basin W190 had the highest index indicating very high vulnerability and the lowest index was 0.2for five (5) sub basins.These results are due to the fact that sub basin W190 has less drainage network computed to those lower indices and hence, has less competence to Chalawa

runoff. A study by smith (2012) agrees with these findings through highlighting the importance of drainage network in reducing flood occurrences and thereby lowering flood vulnerability.

Table 4.3 s: Physical Flood Vulnerability Index of Chalawa Basin in 2012

SUB BASINS	T	D	FVI
W300	456.5	18185	0.03
W290	476.8	15030	0.03
W280	464.6	23381	0.02
W270	457.7	14103	0.03
W260	468.8	9278	0.05
W250	482.9	16886	0.03
W240	471.9	17072	0.03
W230	464	9278	0.05
W220	481	19670	0.02
W210	477.4	23381	0.02
W200	471	20041	0.02
W190	472.6	5010	0.09
W180	483.8	15958	0.03
W170	481	14288	0.03
W160	484	20969	0.02

Source: Authors Analysis (2017)

The environmental flood vulnerability of the Chalawa basin in 2012 is very high with sub basin W290, W220 and W200 have scores of 0.9 indicating very high vulnerability while W190 and W180 have moderate vulnerability. This is a s a result of an increase in urban growth, where settlements are situated on flood plains especially in sub basin W220 where the built up areas have taken over the flood plains of the Salanta streams

and most of the buildings are of low quality. The results confirms Birkmanns (2006b) first school of thought where he looked at vulnerability from the perspective of where a population exposes its self to risk and hazard.

Table 4.3 t: Environmental Flood Vulnerability Index of Chalawa Basin in 2012

SUB BASINS	UG	LU	FVI
W300	34.3	42	0.8
W290	34.3	38	0.9
W280	34.3	44	0.8
W270	34.3	52	0.7
W260	34.3	53	0.6
W250	34.3	39	0.9
W240	34.3	46	0.7
W230	34.3	47	0.7
W220	34.3	38	0.9
W210	34.3	75	0.5
W200	34.3	38	0.9
W190	34.3	82	0.4
W180	34.3	79	0.4
W170	34.3	51	0.7
W160	34.3	62	0.6

Source: Authors Analysis (2017)

4.3.5 Chalawa Flood Vulnerability Index 2035

Table 4.3u, 4.3v, 4.3w, and 4.3x present the level of flood vulnerability in the Jakara basin for 2035.

Table 4.3 u: Social Flood Vulnerability Index of Chalawa in 2035

SUB BASINS	CH	HDI	PG	CM	PE	A/P	CPR	S	WS	ES	FVI
W300	0	0.63	2.6	51.3	0	4	90	1	1	200	0.2
W290	0	0.63	2.6	51.3	0	4	90	1	1	200	0.2
W280	0	0.63	2.6	51.3	0	4	90	1	1	200	0.2
W270	0	0.63	2.6	51.3	0	4	90	1	1	200	0.2
W260	0	0.63	2.6	51.3	0	4	90	1	1	200	0.2
W250	0	0.63	2.6	51.3	0	4	90	1	1	200	0.2
W240	1	0.63	2.6	51.3	0	7	90	1	1	200	0.2
W230	2	0.63	2.6	51.3	0	7	90	1	1	200	0.2
W220	1	0.63	2.6	51.3	32	4	90	1	1	200	0.2
W210	1	0.63	2.6	51.3	46	4	90	1	1	200	0.2
W200	0	0.63	2.6	51.3	27	4	90	1	1	200	0.2
W190	1	0.63	2.6	51.3	23	4	90	1	1	200	0.2
W180	3	0.63	2.6	51.3	63	8	90	1	1	200	0.2
W170	2	0.63	2.6	51.3	71	4	90	1	1	200	0.2
W160	2	0.63	2.6	51.3	57	7	90	1	1	200	0.2

Source: Authors Analysis (2017)

The social vulnerability index of the Chalawa basin in 2035 is generally low due to a predicted rise in coping capacity through increase in Human Development Index (HDI), number of emergency services workers and a decrease in child mortality. This outcome agrees with the study of Nabegu (2013) because it is believed that past experience increase resilliance, awareness and preperedness and hence lower flood vulnerability.

Table 4.3 v: Economic Flood Vulnerability Index of Chalawa in 2035

SUB BASIN	IND	UG	RT	FI	AMINV	FVI
W300	25	54.4	2	1	260	0.3
W290	17	54.4	2	1	130	0.6
W280	12	54.4	2	1	106	0.6
W270	16	54.4	2	1	160	0.4
W260	13	54.4	2	1	130	0.5
W250	11	54.4	2	1	100	0.7
W240	10	54.4	2	1	95	0.7
W230	2	54.4	2	1	72	0.8
W220	6	54.4	2	1	80	0.8
W210	7	54.4	2	1	70	0.9
W200	3	54.4	2	1	72	0.8
W190	6	54.4	2	1	80	0.8
W180	6	54.4	2	1	80	0.8
W170	4	54.4	2	1	78	0.8
W160	6	54.4	2	1	80	0.8

Source: Authors Analysis (2017)

The Chalawa basin in 2035 experienced a rise in flood vulnerability from beign moderately vulnerable to very high vulnerability. In 2012 sub basin W210 was 0.8 but increased to 0.9 in 2035. Other sub basins also increased to 0.7 to 0.8 (W200, W190, W180, W170 and W160). The increased in vulnerability is as a result of a rise in urban growth and a decrease in amount of investment in flood mitigation as revealed by Cutter

(1996), past experience in flood disaster hazards and thereby reduce the amount of investment in flood mitigation.

Table 4.3 w: Physical Flood Vulnerability Index of Chalawa Basin in 2035

SUB BASIN	T	D	FVI
W300	456.5	18185	0.03
W290	476.8	15030	0.03
W280	464.6	23381	0.02
W270	457.7	14103	0.03
W260	468.8	9278	0.05
W250	482.9	16886	0.03
W240	471.9	17072	0.03
W230	464	9278	0.05
W220	481	19670	0.02
W210	477.4	23381	0.02
W200	471	20041	0.02
W190	472.6	5010	0.09
W180	483.8	15958	0.03
W170	481	14288	0.03
W160	484	20969	0.02

Source: Authors Analysis (2017)

The physical vulnerability index for thee Chalawa basin in 2035 is the same with that of 2012. This is because only the natural drainages were coded.

Table 4.3 x: Environmental Flood Vulnerability Index of Chalawa Basin in 2035

SUB BASINS	UG	LU	FVI
W300	54.4	67	0.8
W290	54.4	62.2	0.9
W280	54.4	73	0.7
W270	54.4	61	0.9
W260	54.4	64	0.9
W250	54.4	64	0.9
W240	54.4	72	0.8
W230	54.4	57	0.9
W220	54.4	62.2	0.9
W210	54.4	81	0.7
W200	54.4	62.2	0.9
W190	54.4	91	0.6
W180	54.4	86	0.6
W170	54.4	60	0.9
W160	54.4	71	0.8

Source: Authors Analysis (2017)

Environmental flood vulnerability of the Chalawa basin in 2035 is generally very high. There has been on increase in the basin as a result of a rise in urban growth and land use change sub basins W190 and W180 had scores of 0.6 which indicates high vulnerability, an increase of 0.2 from 2012. Sub basin W270, W260, W230 and W170 had increases in vulnerability from high vulnerability to very high vulnerability. These are as result of change in surfaces from pervious to impervious for example new developments along Chalawa river flood plains, sabuwar Gandu, Zawachikki, Sabuwar Madina and the extreme end of Kumbotso town. The findings by this study fits into the BBC framework where a change in land use increases vulnerability to an event in this case flood.

4.5 FLOOD RISK IN JAKARA AND CHALAWA BASIN

4.5.1 Flood Risk Level in the Jakara Basin

Tables 4.4a, 4.4b and 4.4c present results of the risk level in Jakara basin in 2001, 2012 and 2035.

Table 4.4 a: Flood Risk in Jakara 2001

SUB BASIN	SOCIAL FVI	ECONOMIC FVI	PHYSICAL FVI	ENVIRONMENTAL FVI	AVERAGE FVI	PEAK DISCHARGE	RISK
W340	0.6	0.6	0.3	0.4	0.5	25.0	11.9
W330	0.3	0.4	0.2	0.3	0.3	48.6	14.7
W320	1.0	0.5	0.3	0.6	0.6	28.6	17.2
W310	1.0	0.4	0.2	0.5	0.5	70.2	36.9
W300	0.6	0.5	0.1	0.6	0.4	3.6	1.6
W290	0.8	0.7	0.2	0.6	0.6	34.7	20.2
W280	1.0	0.7	0.2	0.3	0.6	114.2	63.9
W270	0.4	0.4	0.3	0.5	0.4	4.9	2.0
W260	1.0	0.7	0.1	0.6	0.6	4.8	2.9
W250	1.0	0.6	0.2	0.7	0.6	49.8	31.4
W240	1.0	0.5	0.4	0.5	0.6	24.8	14.9
W230	0.9	0.6	0.3	0.6	0.6	23.2	14.1
W220	0.5	0.7	0.5	0.7	0.6	12.2	7.2
W210	1.0	0.6	0.3	0.6	0.6	41.1	26.0
W200	0.9	0.9	0.4	0.8	0.8	12.2	9.3
W190	0.5	0.5	0.7	0.8	0.6	3.4	2.1
W180	0.4	0.7	0.2	0.8	0.5	40.0	20.7
AVERAGE	0.8	0.6	0.3	0.6	0.6	31.8	17.5

Source: Authors Analysis (2017)

The flood risk in the Jakara basin is generally low. Eventhough sub basin W280 had a flood risk index of 63.9 which indicates high risk; the reason for high risk is as a result of high peak discharge (114.2) and also a high vulnerability index. Sub basin W280 is a high population density area and considerably occupies a large area.

Averagely, the social vulnerability is very high while the other physical vulnerability is moderate (see figure 4.8a) the risk is also low on the average, this is attributed to an averagely low peak discharge for the basin.

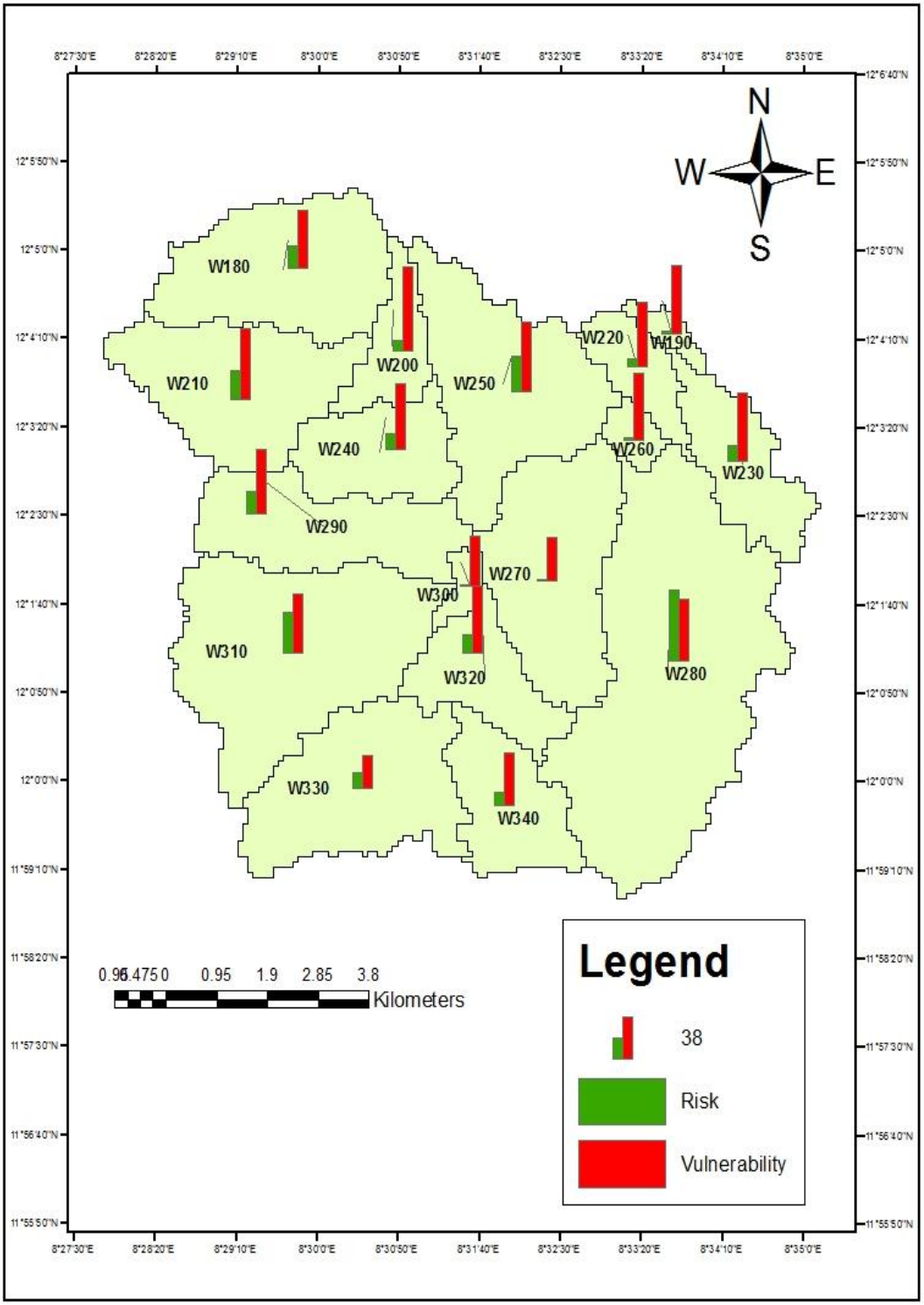


Figure 4.8a: Risk and Vulnerability Map of Jakara Basin 2001
Source: Authors Analysis (2017)

Table 4.4 b: Flood Risk in Jakara 2012

SUB BASIN	SOCIAL FVI	ECONOMIC GVI	ENVIRONMENTAL FVI	PHYSICAL FVI	AVERAGE	PEAK DISCHARGE	RISK
W340	0.4	0.3	0.6	0.3	0.4	30.1	12.4
W330	0.2	0.4	0.5	0.2	0.3	59.8	18.8
W320	0.1	0.5	0.9	0.3	0.4	28.2	12.7
W310	0.1	0.4	0.8	0.2	0.4	84.2	32.5
W300	0.3	0.6	0.8	0.1	0.4	4.7	2.1
W290	0.2	0.8	0.9	0.2	0.5	45.0	23.3
W280	0.2	0.9	0.5	0.2	0.4	137.2	58.7
W270	0.3	0.6	0.7	0.3	0.5	59.6	28.2
W260	0.2	1.0	0.7	0.1	0.5	6.2	3.1
W250	0.1	0.9	0.9	0.2	0.5	61.0	31.5
W240	0.1	0.8	0.7	0.4	0.5	30.0	14.4
W230	0.1	1.0	0.7	0.3	0.5	29.1	14.8
W220	0.5	0.7	0.9	0.5	0.7	16.0	10.5
W210	0.6	0.7	0.7	0.3	0.6	51.2	28.6
W200	0.1	0.6	0.7	0.4	0.4	16.1	7.2
W190	0.4	0.8	0.7	0.7	0.7	4.2	2.8
W180	0.1	0.6	0.7	0.2	0.4	52.1	20.7
AVG	0.2	0.7	0.7	0.3	0.5	42.0	19.0

Source: Authors Analysis (2017)

The flood risk in the Jakara basin in 2012 experienced a rise from 17.5 to 19.0 sub basin W280 aslo recorded a high flood risk with a score of 58.7. The slight drop was as a result of a decrease in average FVI (see figure 4.8b). This further indicates the importance of the vulnerability component in risk reduction as stated by (Birkmann, 2006).

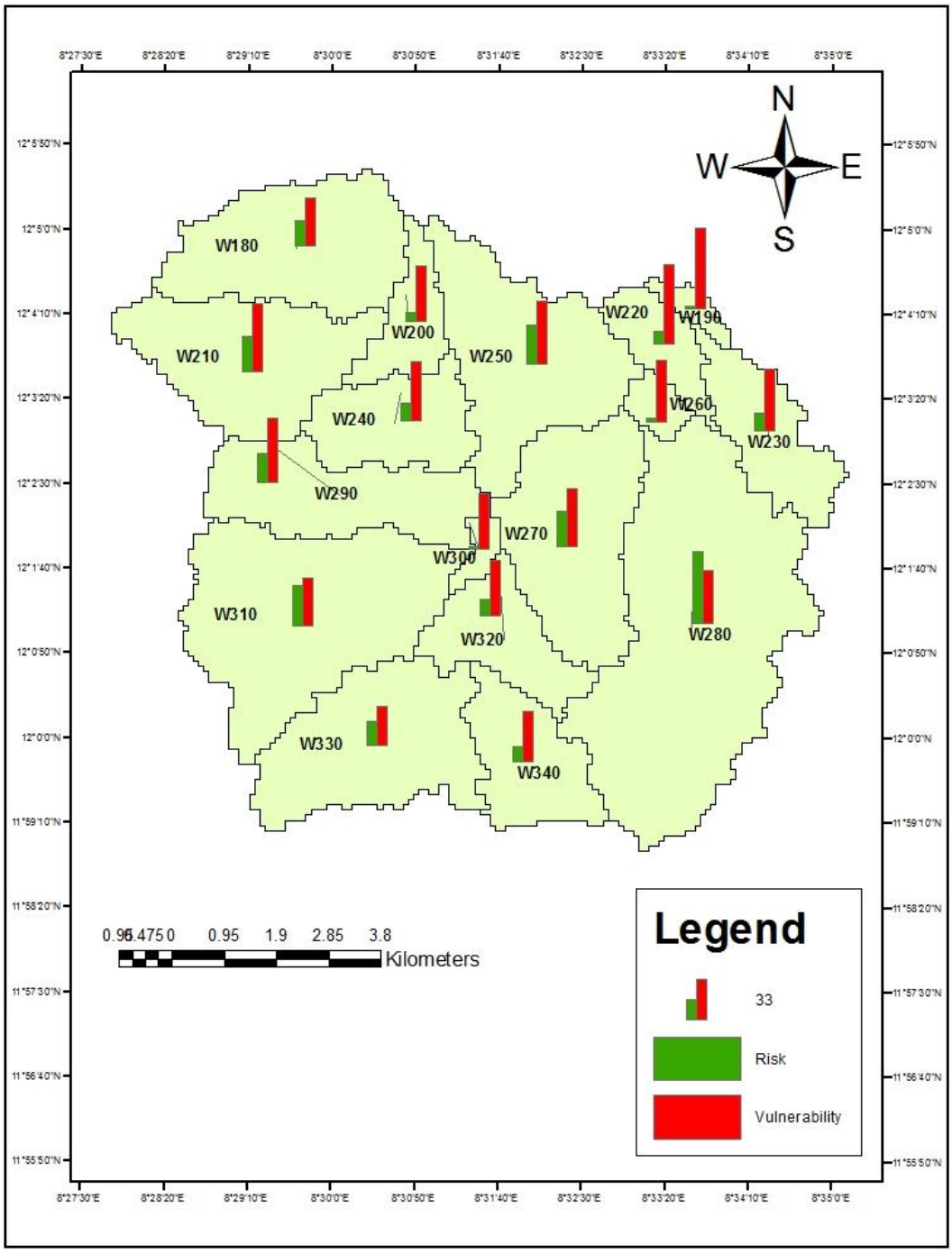


Figure 4.8b: Risk and Vulnerability Map of Jakara Basin 2012
Source: Authors Analysis (2017)

Table 4.4 c: Flood Risk in Jakara 2035

SUB BASIN	SOCIAL FVI	ECONOMIC FVI	PHYSICAL 2035	FVI	AVERAGE	PEAK DISCHARGE	RISK
W340	0.2	0.3	0.36	0.6	0.4	30.7	11.1
W330	0.2	0.3	0.25	0.6	0.3	58.9	19.8
W320	0.2	0.4	0.34	0.6	0.4	27.7	10.3
W310	0.2	0.4	0.21	0.6	0.3	88.3	29.9
W300	0.1	0.4	0.09	0.6	0.3	4.6	1.4
W290	0.1	0.5	0.27	0.8	0.4	45.1	18.1
W280	0.2	0.5	0.15	0.8	0.4	133.4	51.9
W270	0.2	0.4	0.27	0.8	0.4	58.2	24.1
W260	0.2	0.5	0.09	0.8	0.4	6.3	2.5
W250	0.2	0.5	0.18	0.8	0.4	63.1	26.4
W240	0.2	0.5	0.36	0.7	0.4	30.5	13.2
W230	0.2	0.5	0.30	0.9	0.5	28.6	13.2
W220	0.2	0.4	0.44	0.8	0.5	15.8	7.5
W210	0.2	0.5	0.27	0.8	0.4	54.5	22.8
W200	0.2	0.4	0.42	0.8	0.5	17.6	8.0
W190	0.2	0.5	0.75	0.9	0.6	4.7	2.7
W180	0.2	0.4	0.28	0.9	0.4	56.4	24.6
AVG	0.2	0.4	0.30	0.7	0.4	42.6	16.9

Source: Authors Analysis (2017)

The flood risk of the Jakara basin in 2035 is generally low with as average risk of 16.9 sub basin W280 recorded the highest risk with 51.9 indicating high risk, although the level has dropped from 58.7 in 2012 as a result of increase in coping capacity and resilliance which has reduced the vulnerability (figure 4.8c). The peak discharge was as a result of canalization of major parts of the Jakara stream. This finding agrees with the results of Cutter (1996) where a framework emphasized hazard mitigation strategies

through interaction between nature, society and technology with an explicit focus on the locality of analysis.

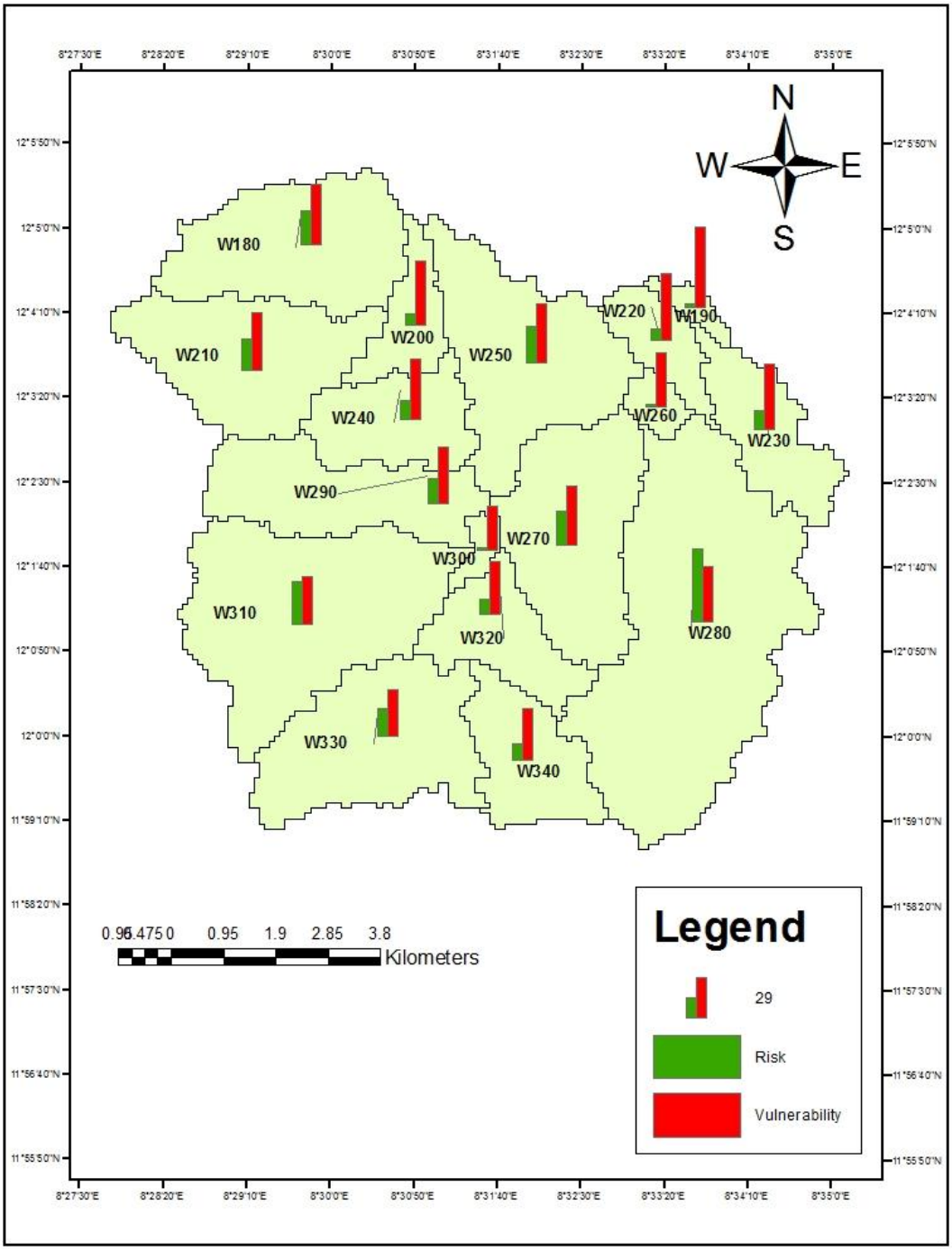


Figure 4.8c: Risk and Vulnerability Map of Jakara Basin 2035
Source: Authors Analysis (2017)

Generally, the flood risk level of Jakara basin is a function of the vulnerability level and hazard in this case the peak discharge. The risk level in the Jakara basin shows a pattern where sub basins with large areas, high vulnerability and high peak discharge had higher risks. Sub basins W280 and W190 are a contrast where W280 has a large area (20.3km2) average vulnerability of 0.6 and a peak discharge of (137.2cm3/sec) and hence a high risk (see figures 4.8a,b,c). This sub basins houses Fagge, Kwarin Gogau, Jakara, Bakin Ruwa, Noamans Land and several other flood prone areas. Sub basin W190 has an area of (7.09km2) an average vulnerability of 0.6 and a peak discharge of 4.7cm3/sec and the reason for the low risk. Theses agree with that of Birkmann (2006c), Birkmann (2007), Bates (2005) where their study revealed the link between risk vulnerability and hazard. The average flood risk also had a fluctuation with a rise in 2012 and a fall in flood risk level 2035 as a result of reduction in the flood vulnerability level.

The flood risk level of the Jakara basin is a function of the vulnerability level and hazard in this case the peak discharge. The risk level in the Jakara basin shows a pattern where sub-basins with large area coverage, high vulnerability and high peak discharge have higher risk. Sub-basin W280 and W190 are a contrast where W280 has an area of high vulnerability (0.7) and high peak discharge (0.9) and thereby high risk (0.9), while the latter has lower peak discharge, lower vulnerability and lower risk (Figure 4.4a, 4.4b and 4.4c). These findings agree with that of Brinkman (2007); Birkmann (2006a) and Bates (2005) where their study revealed the link between risk, vulnerability and discharge. The average flood risk also had a fluctuation with a rise in 2012 and a fall in flood risk level of 2035 as a result of a reduction in the flood vulnerability level.

4.5.2 Flood Risk Level in the Chalawa Basin

Tables 4.4d, 4.4e and 4.4f present results of the risk level in Chalawa basin in 2001, 2012 and 2035.

Table 4.4 d: Flood Risk in Chalawa 2001

SUB BASIN	SOCIAL FVI	ENVIRONMENTAL FVI	ECONOMIC FVI	PHYSICAL FVI	AVERAGE	PEAK DISCHARGE	RISK
W300	0.7	0.7	0.2	0.03	0.4	17.9	7.2
W290	0.8	0.6	0.4	0.03	0.4	17	7.6
W280	0.8	0.5	0.3	0.02	0.4	36.9	14.5
W270	0.7	0.4	0.3	0.03	0.4	19.8	7.1
W260	0.7	0.4	0.4	0.05	0.4	6.8	2.7
W250	0.8	0.6	0.8	0.03	0.6	20.3	11.2
W240	0.7	0.5	0.8	0.03	0.5	31.6	16.8
W230	0.7	0.5	0.8	0.05	0.5	3.7	1.9
W220	0.6	0.6	0.5	0.02	0.4	49.2	21.7
W210	0.5	0.3	0.4	0.02	0.3	93.2	27.5
W200	0.4	0.7	0.7	0.02	0.5	19.9	9.2
W190	0.5	0.4	0.8	0.09	0.4	3.1	1.3
W180	0.4	0.3	0.8	0.03	0.4	34.4	13.1
W170	0.4	0.3	0.8	0.03	0.4	42.3	17.0
W160	0.6	0.5	0.8	0.02	0.5	72.3	35.4
AVERAGE	0.6	0.5	0.6	0.03	0.4	31.2	13.0

Source: Authors Analysis (2017)

The flood risk of the Chalawa basin in 2001 resembles that of Jakara basin in 2001, but with lower values. Sub basins W160 recorded the highest risk with 35.4 indicating moderate risk. Sub basins W190 recorded the lowest risk with 1.3 indicating very low risk (figure 4.8d). The Chalawa basin recorded much lower vulnerability and peak discharge and hence the reason for much lower flood risk. This further reveals the importance of the components of flood risk as confirmed by the findings of Cardona et.al. (2010) where individual sub basins contribute to the overall outcome of flood risk.

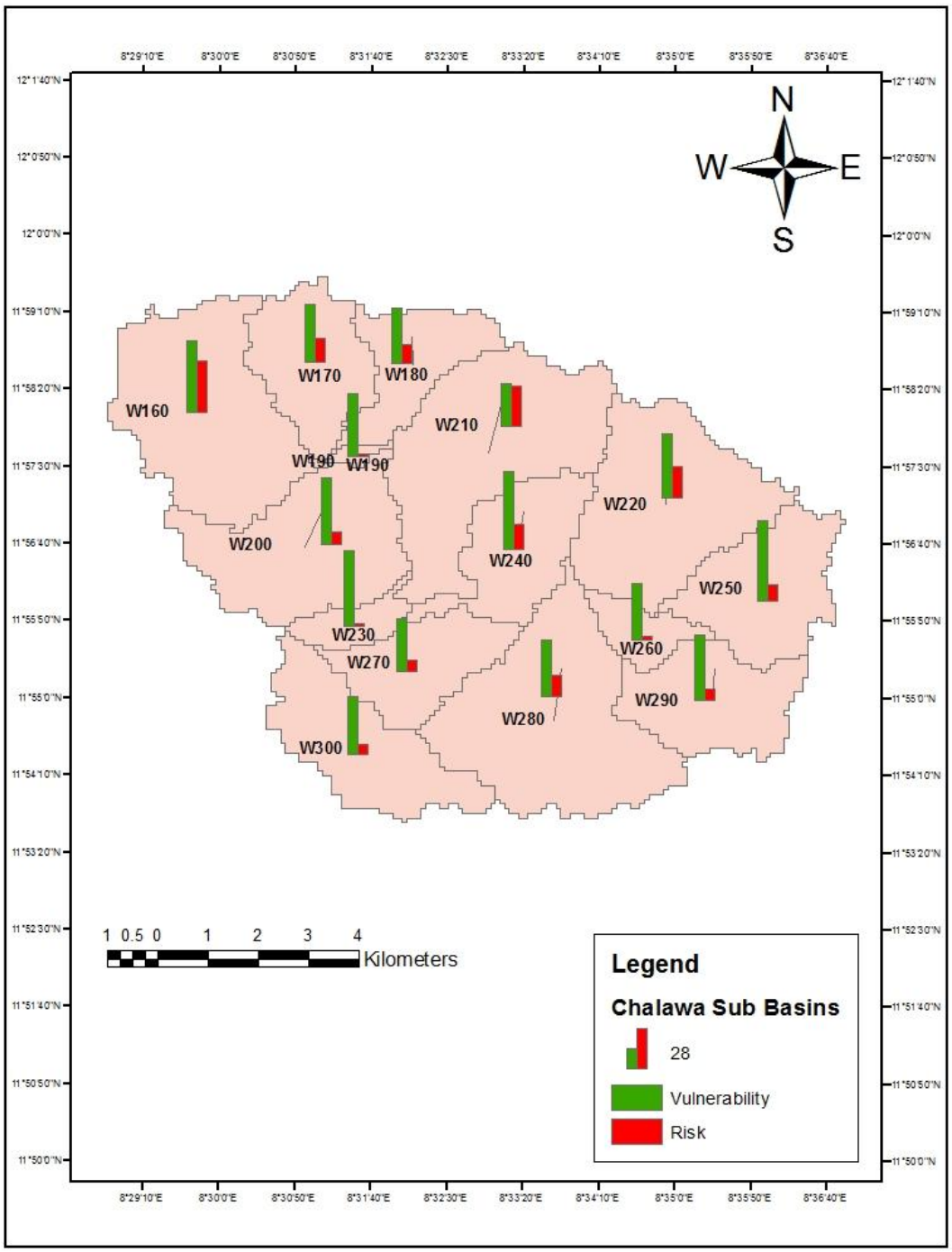


Figure 4.8d: Risk and Vulnerability Map of Chalawa Basin 2001
Source: Authors Analysis (2017)

Table 4.4 e: Flood Risk in Chalawa 2012

SUB BASIN	SOCIAL	ENVIRONMENTAL	PHYSICAL FVI	ECONOMIC	AVERAGE	PEAK DISCHARGE	RISK
W300	0.6	0.8	0.03	0.3	0.4	45.0	19.1
W290	0.6	0.9	0.03	0.5	0.5	39.0	19.9
W280	0.6	0.8	0.02	0.3	0.4	83.0	35.9
W270	0.6	0.7	0.03	0.4	0.4	37.0	15.3
W260	0.6	0.6	0.05	0.4	0.4	13.0	5.5
W250	0.6	0.9	0.03	0.5	0.5	40.0	19.8
W240	0.6	0.7	0.03	0.5	0.5	37.0	17.2
W230	0.6	0.7	0.05	0.8	0.5	12.0	6.4
W220	0.5	0.9	0.02	0.7	0.5	71.0	38.8
W210	0.5	0.5	0.02	0.6	0.4	80.0	32.6
W200	0.6	0.9	0.02	0.8	0.6	63.0	35.3
W190	0.6	0.4	0.09	0.7	0.4	2.7	1.2
W180	0.5	0.4	0.03	0.7	0.4	30.0	12.4
W170	0.5	0.7	0.03	0.7	0.5	40.0	19.2
W160	0.5	0.6	0.02	0.7	0.5	80.0	36.0
AVG	0.6	0.7	0.03	0.6	0.5	44.8	21.0

Source: Authors Analysis (2017)

The flood risk of Chalawa basin 2012 had an increase compared to 2001. The average risk (21.0) is as a result of an increase in average peak discharge and flood vulnerability. Sub basins W220 recorded the highest risk 38.8 indicating moderate vulnerability this increase compared to 2001 is as a result of the rise in flood vulnerability from moderate to high and also the drastic increase in surface runoff from 49.2 to 71.0cm^3/sec. This is due to change from pervious surfaces to impervious surfaces especially urban growth (4.8e). Sub basins W190 recorded thee lowest flood risk with score of 1.2 indicating

very little risk. There was a decrease in flood risk within this basin compared to 2001 as a result of a drop in the peak discharge (hazard). These findings fit into Pressure and Release model (PAR) by Blaike (2004) where risk is a product of two pressure sources: a natural hazard and a vulnerable situation.

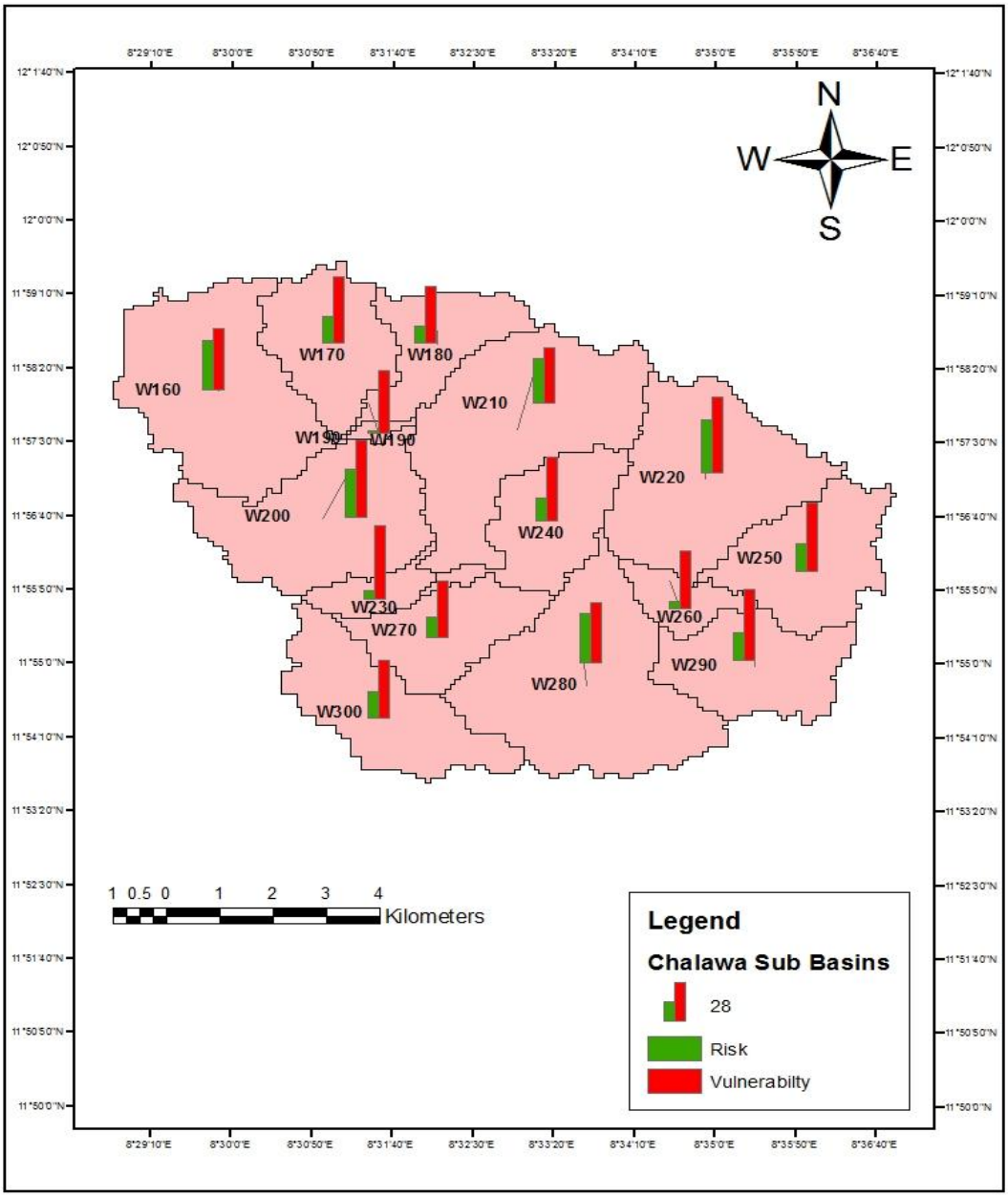


Figure 4.8e: Risk and Vulnerability Map of Chalawa Basin 2012
Source: Authors Analysis (2017)

Table 4.4 f: Flood Risk in Chalawa 2035

SUB BASIN	ENVIRONMENTAL	PHYSICAL FVI	SOCIAL FVI	FVI	AVERAGE	PEAK DISCHARGE	RISK
W300	0.8	0.03	0.2	0.3	0.3	43.2	14.4
W290	0.9	0.03	0.2	0.6	0.4	21.8	9.0
W280	0.7	0.02	0.2	0.6	0.4	73	29.0
W270	0.9	0.03	0.2	0.4	0.4	33.7	13.1
W260	0.9	0.05	0.2	0.5	0.4	10.9	4.4
W250	0.9	0.03	0.2	0.7	0.4	27.5	11.9
W240	0.8	0.03	0.2	0.7	0.4	37.9	15.7
W230	1.0	0.05	0.2	0.8	0.5	7.9	3.9
W220	0.9	0.02	0.2	0.8	0.5	72.5	33.3
W210	0.7	0.02	0.2	0.9	0.4	84	36.7
W200	0.9	0.02	0.2	0.8	0.5	64.2	30.2
W190	0.6	0.09	0.2	0.8	0.4	2.7	1.1
W180	0.6	0.03	0.2	0.8	0.4	30.6	12.2
W170	0.9	0.03	0.2	0.8	0.5	39	18.1
W160	0.8	0.02	0.2	0.8	0.4	78.9	33.9
AVG	0.8	0.03	0.2	0.7	0.4	41.9	17.8

Source: Authors Analysis (2017)

The flood risk of Chalawa in 2035 is averagely low (17.8), this is attributed to a drop in the average flood vulnerability of the basin (0.4). Sub basin W210 recorded the highest flood risk with 36.7 indicating moderate vulnerability (figure 4.8f). This is as a result of an increase in peak discharge as a result of of a drastic rise in urban growth. Sub basin W190 still maintained the lowest flood risk amongs the sub basins with 1.1 indicating very low risk.

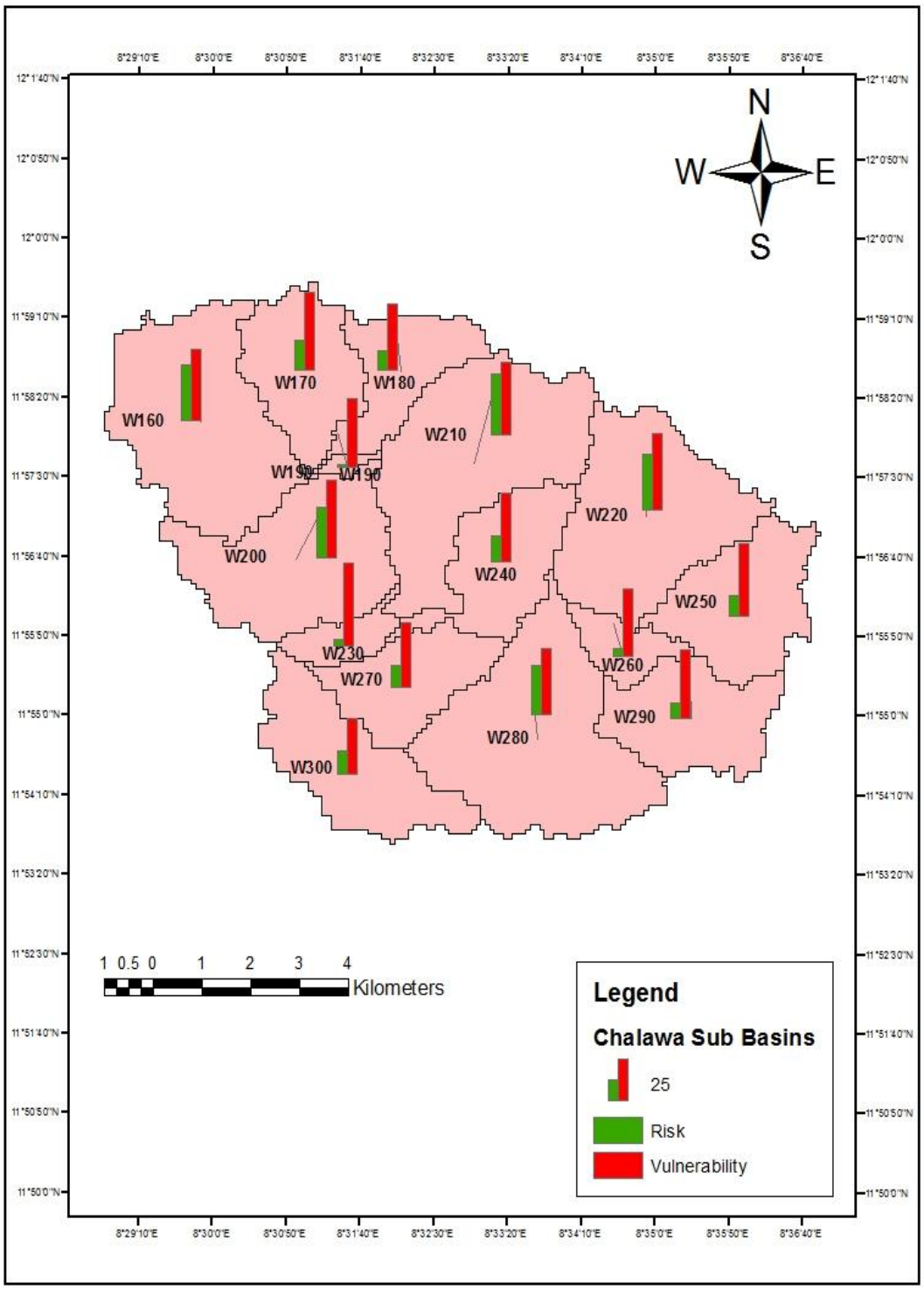


Figure 4.8f: Risk and Vulnerability Map of Chalawa Basin 2035
Source: Authors Analysis (2017)

Generally the flood risk pattern in the Chalawa basin resembles that of Jakara but with slight difference. In 2001 sub-basin W210 had an average vulnerability of 0.3, 93.2 peak discharges and risk of 27.5, but sub-basin W160 had a lower discharge and a higher vulnerability and hence a higher flood risk (see figure 4.8d). The lowest risk was recorded in sub-basin W190 which has a small area, low vulnerability and hence lower risk. The general pattern shows a rise in risk level in 2012 and a drop in 2035 due to decrease in flood vulnerability as a result of an increase in resilliance and coping capacity and a fuher decrease in peak discharge due to the construction of a canal that conveys up 40cm^3/sec of run off out of the basin. This finding agrees with the study of Green (2004) and De Leon (2006) which also emphasised the effect of the components of risk on the probable outcome. The entire study could be hinged on the BBC frame work by Birkmann (2006).

CHAPTER FIVE

SUMMARY, CONCLUSION AND RECOMMENDATIONS

5.1 SUMMARY

- The metropolis is made up of two (2) drainage basins: Jakara and Chalawa. The Jakara basin is made up of 17 sub-basins while the Chalawa basin has 15 sub-basins.

- The LULC change from 2001, 2012 and 2035 shows an increase in built- up areas from 19.7% to 34.3% to 54.4% this indicates an increase of over 50% in impervious surfaces.

- The amount of runoff within the Jakara basin in 2001, 2012 and 2035 revealed an increased in runoff all through as a result of increase in built up areas across the basin.

- The Chalawa basin had an increase between 2001 and 2012 but a decreased was recorded in 2035 as a result of the canalization of the Panshekara and Madobi road within the basin.

- The result in the Chalawa basin shows an increase in vulnerability from 0.4 to 0.5 and a decline to 0.4 in 2001, 2012 and 2035 respectively. In the Jakara basin the flood vulnerability level drop from 0.6 to 0.5 and to 0.4 in 2001, 2012 and 2035 respectively. This indicated a rise in most of the indicators that reduce vulnerability.

- The flood risk followed the same pattern with that of flood vulnerability. In the Jakara basin the risk level moved from 17.5 to 19.0 and dropped to 16.9 in 2001, 2012 and 2035 respectively. The Chalawa basin also had a risk level of 13.0 in 2001, 21.0 in 2012 and 17.8 in 2035. Generally it was observed that landuse and landcover have a significant influence on runoff which greatly influence flood vulnerability and risk levels.

5.2 Conclusion

Land use and land cover (LULC) change detection has proven to be an efficient method for analyzing the extent of change from pervious surfaces to impervious surfaces in the study area. The LULC maps produced at the sub-drainage basin level have proven to show the amount of change in LULC which is found to be better than the generalized classification of the entire drainage basin. This has shed more light on the response of each changing sub-basin to rainfall events and its subsequent effect. Generally the increase of impervious surfaces from 2001-2035 have indicated a massive increase in run-off within the study area.

The use of HEC-HMS model has improved information on run-off volume in the study area which is ungauged. The fragmentation of the drainage basin into sub-basin has provided data on run off volume at sub-drainage basin level. Hence this method can be used to provide information on future flood occurrences through simulation of possible scenarios of rainfall event on a changing drainage basin.

Vulnerability assessment of the study area through the use of Balica (2007) method has proven to be a better method than the conventional methods used. The methods have shown to be all encompassing of all the flood vulnerability components (social,

economic, physical and environment). The interplay of indicators within the components that either increase or decrease vulnerability in the study area has given an insight on the vulnerability level in each sub-basin. It was revealed that the highlyurbanized sub-basins had vulnerability than the less urbanized ones. It was also highlighted that social vulnerability constituted the highest score which agrees with theoretical principles.

The Sengtianthr approach of flood risk analysis has proven that risk is a function of hazard (peak discharge) and vulnerability. The entire study fits squarely into established theoretical and conceptual framework currently in use in this field of study.

Generally the study observed that there were areas of high and low vulnerability and risk especially the highly urbanized and larger sub-basins and the less urbanized and smaller sub-basins respectively.

5.3 Contribution to Gap in Knowledge

1. This study has contributed to the literature of Hydro-informatics and specifically on the application of hydrologic model (HEC-HMS) to quantify the volume of run off in an unguage drainage basin and sub-basins.
2. The application of the Balica (2012) Flood Vulnerability Index (FVI) method to examine level of flood vulnerability has provided knowledge on the influence of these components to flood vulnerability level at sub-basin level in the study area.
3. This study has shown the possibility of merging flood hazard and vulnerability in order to derive flood risk of the study area. This is considered a valid contribution to existing literature on flood risk analysis which is mostly conventional.

4. In addition a relationship has been established between land use and land cover change, surface runoff volume, flood vulnerability and flood risk.

5.4 Recommendations

The findings of this study have demonstrated the capabilities of HEC-HMS, ArcGIS, HECGeoHMS, ArcHydro and Flood Vulnerability Index in analyzing flood vulnerability and risk. Based on this, the following are recommended:

1. The Kano State Government through the Ministry of Land and Survey should produce flood mitigation plans and policies and ensure compliance by the general public.
2. Canals and sewers should be built by the Ecological Fund Office across the metropolis to convey flood waters and delay discharge into the Chalawa and Jakara rivers.
3. Surveys should be conducted more often by the National Bureau of Statistics and its sister organisations on the major indicators of the components of flood vulnerability, so as to know if the flood vulnerability is rising or declining.
4. Gauging stations should be established possibly at junctions of sub-drainage basins of the study area by agencies responsible, such as the Ministry of Water Resources, Nigeria Hydrologic Agency and the River Basin Development Authorities in order to enhance data collection and flood mitigation strategies.

5.5 Recommendations for Further Studies

1. A study should be conducted using HEC-RAS in order to investigate relationships between run-off velocity, depth and extent of flood waters.

2. A study should also be conducted using Connor and Hiroki flood vulnerability index approach as a way of comparing its capability with the one suggested by Belica (2012).
3. A study should also be conducted using LiDaR validation method in order to compare and validate the simulated flood imageries with the high resolution LiDaR imageries.

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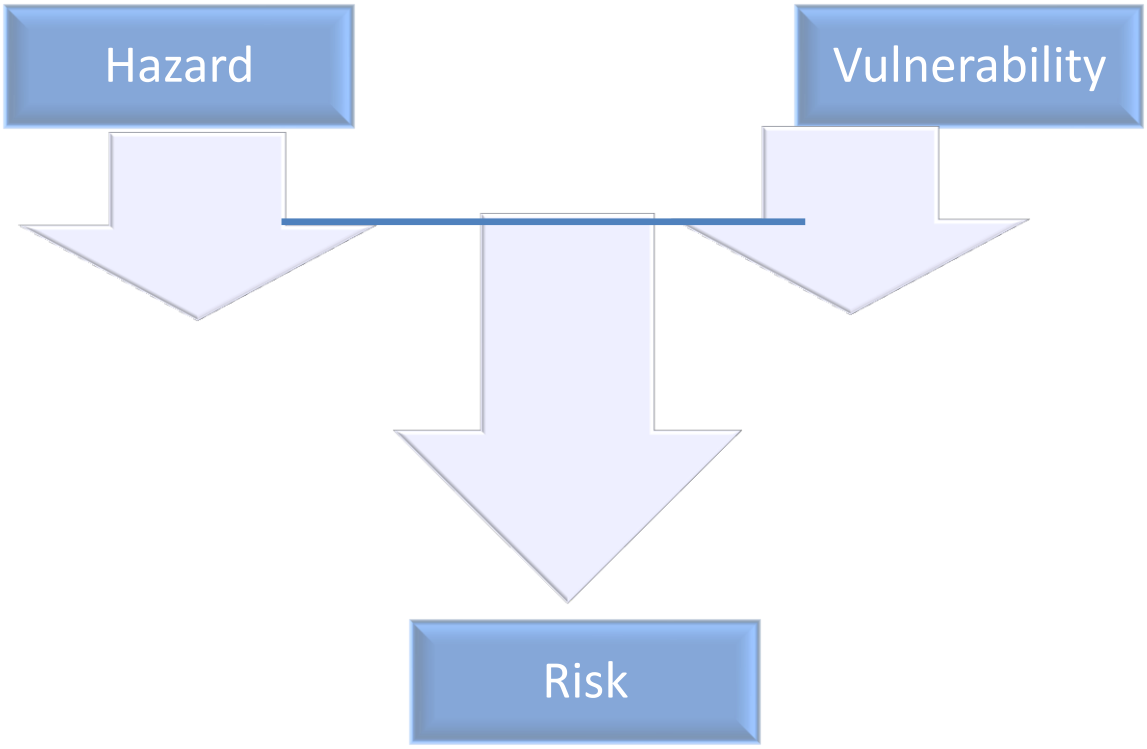
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APPENDIX I

SENGTIANTHR RISK APPROACH



APPENDIX II

Land Use Land Cover Change

Class	2001			2012			2035		
	Area (Ha)	%	kmsq	Area (Ha)	%	kmsq	Area (Ha)	%	kmsq
Built up	15087.6	19.7	150.9	26342.19	34.3	263.4	41718.06	54.4	417.2
Forest	12436.92	16.2	124.4	3700.98	4.8	37.0	1999.26	2.6	19.9
Farmland	46241.37	60.3	462.5	38482.38	50.2	384.8	27699.66	36.1	276.9
Water	1344.24	1.8	13.4	1245.24	1.6	12.5	818.91	1.1	8.2
Bare land	1612.35	2.1	16.1	6951.69	9.1	69.5	4486.59	5.8	44.9
Total	76722.48	100	767.23	76722.48	100	767.2	76722.48	100	767.2

APPENDIX III

FLOOD VULNERABILITY INDICES

FVI_S

P_D	Population Density	
P_{FA}	Population in flood prone area	
C_H	Cultural Heritage	No. of historical buildings. Museum etc.
P_G	Population growth	% of population growth in urban area in the last 10 years
HDI	Human Development Index	$HDI = \frac{1}{3}(\text{LEI}) + \frac{1}{3}(EI) + \frac{1}{3}(GI)$
C_M	Child Mortality	No. of children less than 1 year draw per 1000
P_E	Past experience	No. of people affected in the last 10years because of flood
A/P	Awareness and preparedness	Range between 1-10
C_{PR}	Communication penetration rate	% of household with source of information
S	Shelter and hospitals	No. of shelters per Km^2 including hospitals
W_S	Warning system	If no. ws their value is 1, If yes ws their value is 10
E_S	Emergency services	Number of people working in the services

E_R	Evacuation Roads	% of asphalts roads
U_{PA}	Unpopulated Area	
FVI_{EC}		
I_{ND}	Industries	No. of industries or any types of economic alter in urban area
C_R	Contact with River	Of city along river km
U_M	Unemployment	No. of people unemployed/total population working x 100
I_{neq}	Inequality	Gini coefficient for wealth in equality between 0 and 1
U_G	Urban growth	% of increase in urban area in the last 10 years past urban growth may result in poor quality housing and the make people
R_T	Recovery time	Amount of time needed by the city to recover to a functional operation after flood event
F_I	Flood Insurance	The no.of flood insurance per 100 inhabitants
A_MI_{nv}	Amount of investment	If 0 there take 1
D_{SC}	Dams storage capacity	
D	Dikes and levees	
FVI_{ph}		
T	Topography	Relief average slope of the city
C_R	Contact with river	

Ev/Rainfall	Evaporation rate/rainfall	
Sc/Vyear	Storage capacity over yearly discharge	
D	Drainage system	KM of canalization of the city
L	Life Expectancy Index	LEI=(LE-25)/(85-25)
FVI_{EN}		
U_G	Urban growth	
Rainfall	Average rainfall/yr	
E_V	Evaporation rate	
L_U	Land use % of areas used for built up, forest, water bodies	

APPENDIX IV

Chalawa HMS Curve Number

Table

Subbasin1

OBJECTID *	Shape *	grid_code	Shape_Length	Shape_Area	HydroID	DrainID	Name	Description	PrecipGage	TotStormP	BasinSlope	LossMet	TransMet	BaseMet	PctImp	InitAbst	BasinCN
1	Polygon	1	20969.088	11923176.364413	16	16	W160	<Null>	Precip Gage 1	<Null>	484.381226	SCS	SCS	<Null>	<Null>	<Null>	90
2	Polygon	2	14288.6704	5931457.36223	17	17	W170	<Null>	Precip Gage 2	<Null>	481.997101	SCS	SCS	<Null>	<Null>	<Null>	83
3	Polygon	3	15958.775	4631529.964346	18	18	W180	<Null>	Precip Gage 3	<Null>	483.810394	SCS	SCS	<Null>	<Null>	<Null>	90
4	Polygon	4	5010.3128	404613.15381	19	19	W190	<Null>	Precip Gage 4	<Null>	472.617035	SCS	SCS	<Null>	<Null>	<Null>	90
5	Polygon	5	20041.252	9805413.732582	20	20	W200	<Null>	Precip Gage 5	<Null>	471.210724	SCS	SCS	<Null>	<Null>	<Null>	79
6	Polygon	6	23381.4612	12689358.791951	21	21	W210	<Null>	Precip Gage 6	<Null>	477.36499	SCS	SCS	<Null>	<Null>	<Null>	81
7	Polygon	7	19670.118	11096732.417543	22	22	W220	<Null>	Precip Gage 7	<Null>	481.148956	SCS	SCS	<Null>	<Null>	<Null>	80
8	Polygon	8	9278.3572	1721758.339399	23	23	W230	<Null>	Precip Gage 8	<Null>	464.109985	SCS	SCS	<Null>	<Null>	<Null>	82
9	Polygon	9	17072.178	5724846.424225	24	24	W240	<Null>	Precip Gage 9	<Null>	471.918793	SCS	SCS	<Null>	<Null>	<Null>	80
10	Polygon	10	16886.6108	6800945.421143	25	25	W250	<Null>	Precip Gage 10	<Null>	482.874695	SCS	SCS	<Null>	<Null>	<Null>	80
11	Polygon	11	9278.3572	2023066.05668	26	26	W260	<Null>	Precip Gage 11	<Null>	468.812775	SCS	SCS	<Null>	<Null>	<Null>	80
12	Polygon	12	14103.103	5096404.591098	27	27	W270	<Null>	Precip Gage 12	<Null>	457.714539	SCS	SCS	<Null>	<Null>	<Null>	80
13	Polygon	13	23381.4606	13541629.211613	28	28	W280	<Null>	Precip Gage 13	<Null>	464.553711	SCS	SCS	<Null>	<Null>	<Null>	82
14	Polygon	14	15030.9388	6232765.005286	29	29	W290	<Null>	Precip Gage 14	<Null>	476.860504	SCS	SCS	<Null>	<Null>	<Null>	81
15	Polygon	15	18185.5804	7291646.465016	30	30	W300	<Null>	Precip Gage 15	<Null>	456.48877	SCS	SCS	<Null>	<Null>	<Null>	80

Jakara HMS Curve Number

Table

Subbasin1

OBJECTID *	Shape *	grid_code	Shape_Length	Shape_Area	HydrolD	DrainID	Name	Description	PrecipGage	TotStormP	BasinSlope	LossMet	TransMet	BaseMet	PctImp	InitAbst	BasinCN
1	Polygon	1	17072.1774	8600182.807785	18	18	W180	<Null>	Precip Gage 1	<Null>	481.634644	SCS	SCS	<Null>	<Null>	<Null>	81
2	Polygon	2	5938.1486	705920.908205	19	19	W190	<Null>	Precip Gage 2	<Null>	443.951233	SCS	SCS	<Null>	<Null>	<Null>	82
3	Polygon	3	11134.029	2660116.593454	20	20	W200	<Null>	Precip Gage 3	<Null>	468.990295	SCS	SCS	<Null>	<Null>	<Null>	80
4	Polygon	4	18000.0132	8238613.580449	21	21	W210	<Null>	Precip Gage 4	<Null>	485.077332	SCS	SCS	<Null>	<Null>	<Null>	82
5	Polygon	5	10206.1932	2401852.821205	22	22	W220	<Null>	Precip Gage 5	<Null>	448.935486	SCS	SCS	<Null>	<Null>	<Null>	84
6	Polygon	6	15216.5064	4364657.395666	23	23	W230	<Null>	Precip Gage 6	<Null>	460.972382	SCS	SCS	<Null>	<Null>	<Null>	97
7	Polygon	7	12989.7006	4614312.223033	24	24	W240	<Null>	Precip Gage 7	<Null>	473.205231	SCS	SCS	<Null>	<Null>	<Null>	84
8	Polygon	8	20597.9534	9555758.728925	25	25	W250	<Null>	Precip Gage 8	<Null>	462.024323	SCS	SCS	<Null>	<Null>	<Null>	86
9	Polygon	9	5195.8802	955575.884027	26	26	W260	<Null>	Precip Gage 9	<Null>	446.918915	SCS	SCS	<Null>	<Null>	<Null>	86
10	Polygon	10	17257.745	8806793.782904	27	27	W270	<Null>	Precip Gage 10	<Null>	462.152496	SCS	SCS	<Null>	<Null>	<Null>	90
11	Polygon	11	30804.1472	20273704.205655	28	28	W280	<Null>	Precip Gage 11	<Null>	472.231842	SCS	SCS	<Null>	<Null>	<Null>	88
12	Polygon	12	18000.0142	6818163.014002	29	29	W290	<Null>	Precip Gage 12	<Null>	480.319458	SCS	SCS	<Null>	<Null>	<Null>	91
13	Polygon	13	5195.8802	688703.268956	30	30	W300	<Null>	Precip Gage 13	<Null>	463.174988	SCS	SCS	<Null>	<Null>	<Null>	90
14	Polygon	14	22453.6252	13352235.838631	31	31	W310	<Null>	Precip Gage 14	<Null>	482.947784	SCS	SCS	<Null>	<Null>	<Null>	94
15	Polygon	15	13917.5362	4201090.337743	32	32	W320	<Null>	Precip Gage 15	<Null>	471.383209	SCS	SCS	<Null>	<Null>	<Null>	97
16	Polygon	16	19298.9838	8901490.45084	33	33	W330	<Null>	Precip Gage 16	<Null>	486.069641	SCS	SCS	<Null>	<Null>	<Null>	97
17	Polygon	17	13360.835	4640138.686547	34	34	W340	<Null>	Precip Gage 17	<Null>	482.651215	SCS	SCS	<Null>	<Null>	<Null>	98

APPENDIX V

DAILY RAINFALL IN KANO METROPOLIS 2001 AND 2012

Daily rainfall (mm) in Kano, Kano State

Month	Day	2001	2012
Jan	1	0.0	0.0
Jan	2	0.0	0.0
Jan	3	0.0	0.0
Jan	4	0.0	0.0
Jan	5	0.0	0.0
Jan	6	0.0	0.0
Jan	7	0.0	0.0
Jan	8	0.0	0.0
Jan	9	0.0	0.0
Jan	10	0.0	0.0
Jan	11	0.0	0.0
Jan	12	0.0	0.0
Jan	13	0.0	0.0
Jan	14	0.0	0.0
Jan	15	0.0	0.0
Jan	16	0.0	0.0
Jan	17	0.0	0.0

Jan	18	0.0	0.0
Jan	19	0.0	0.0
Jan	20	0.0	0.0
Jan	21	0.0	0.0
Jan	22	0.0	0.0
Jan	23	0.0	0.0
Jan	24	0.0	0.0
Jan	25	0.0	0.0
Jan	26	0.0	0.0
Jan	27	0.0	0.0
Jan	28	0.0	0.0
Jan	29	0.0	0.0
Jan	30	0.0	0.0
Jan	31	0.0	0.0
Feb	1	0.0	0.0
Feb	2	0.0	0.0
Feb	3	0.0	0.0
Feb	4	0.0	0.0
Feb	5	0.0	0.0
Feb	6	0.0	0.0
Feb	7	0.0	0.0
Feb	8	0.0	0.0
Feb	9	0.0	0.0
Feb	10	0.0	0.0
Feb	11	0.0	0.0
Feb	12	0.0	0.0
Feb	13	0.0	0.0
Feb	14	0.0	0.0
Feb	15	0.0	0.0
Feb	16	0.0	0.0
Feb	17	0.0	0.0
Feb	18	0.0	0.0
Feb	19	0.0	0.0
Feb	20	0.0	0.0
Feb	21	0.0	0.0
Feb	22	0.0	0.0
Feb	23	0.0	0.0
Feb	24	0.0	0.0
Feb	25	0.0	0.0
Feb	26	0.0	0.0
Feb	27	0.0	0.0
Feb	28	0.0	0.0
Feb	29	*	0.0
Mar	1	0.0	0.0

Mar	2	0.0	0.0
Mar	3	0.0	0.0
Mar	4	0.0	0.0
Mar	5	0.0	0.0
Mar	6	0.0	0.0
Mar	7	0.0	0.0
Mar	8	0.0	0.0
Mar	9	0.0	0.0
Mar	10	0.0	0.0
Mar	11	0.0	0.0
Mar	12	0.0	0.0
Mar	13	0.0	0.0
Mar	14	0.0	0.0
Mar	15	0.0	0.0
Mar	16	0.0	0.0
Mar	17	0.0	0.0
Mar	18	0.0	0.0
Mar	19	0.0	0.0
Mar	20	0.0	0.0
Mar	21	0.0	0.0
Mar	22	0.0	0.0
Mar	23	0.0	0.0
Mar	24	0.0	0.0
Mar	25	0.0	0.0
Mar	26	0.0	0.0
Mar	27	0.0	0.0
Mar	28	0.0	0.0
Mar	29	0.0	0.0
Mar	30	0.0	0.0
Mar	31	0.0	0.0
Apr	1	4.5	0.0
Apr	2	0.0	0.0
Apr	3	0.0	0.0
Apr	4	0.0	0.0
Apr	5	0.0	0.0
Apr	6	0.0	0.0
Apr	7	0.0	0.0
Apr	8	0.0	0.0
Apr	9	0.0	0.0
Apr	10	0.0	0.0
Apr	11	0.0	0.0
Apr	12	0.0	0.0
Apr	13	0.0	0.0
Apr	14	0.0	0.0

Apr	15	0.0	0.0
Apr	16	0.0	0.0
Apr	17	0.0	0.0
Apr	18	0.0	0.0
Apr	19	0.0	0.0
Apr	20	0.0	0.0
Apr	21	0.0	0.0
Apr	22	0.0	0.0
Apr	23	0.0	0.0
Apr	24	0.0	0.0
Apr	25	0.0	0.0
Apr	26	0.0	0.0
Apr	27	0.0	0.0
Apr	28	36.6	0.0
Apr	29	0.0	0.0
Apr	30	0.0	0.0
May	1	5.6	0.0
May	2	0.0	0.0
May	3	0.0	0.0
May	4	0.0	0.0
May	5	88.8	0.0
May	6	0.0	0.0
May	7	0.0	0.6
May	8	0.0	13.9
May	9	0.0	0.0
May	10	0.0	0.0
May	11	0.0	0.0
May	12	22.6	0.0
May	13	0.0	0.0
May	14	37.5	0.0
May	15	0.0	0.0
May	16	0.0	0.0
May	17	0.0	0.0
May	18	0.0	0.0
May	19	0.0	0.0
May	20	0.0	0.0
May	21	0.0	0.0
May	22	0.0	0.0
May	23	0.0	0.0
May	24	0.0	0.0
May	25	0.0	0.0
May	26	0.0	0.0
May	27	0.0	0.0
May	28	31.3	0.0

May	29	0.0	9.8
May	30	0.0	47.6
May	31	0.0	0.0
Jun	1	24.4	0.0
Jun	2	0.0	50.6
Jun	3	0.0	0.0
Jun	4	9.8	0.0
Jun	5	0.0	0.0
Jun	6	49.8	0.0
Jun	7	0.0	3.9
Jun	8	20.8	0.0
Jun	9	0.0	4.2
Jun	10	0.0	0.0
Jun	11	0.0	25.8
Jun	12	0.0	0.0
Jun	13	0.5	7.5
Jun	14	0.0	0.0
Jun	15	0.0	35.5
Jun	16	3.3	0.0
Jun	17	29.2	0.0
Jun	18	0.0	0.0
Jun	19	0.0	81.9
Jun	20	30.7	0.0
Jun	21	0.0	0.0
Jun	22	0.0	12.9
Jun	23	34.5	53.6
Jun	24	4.5	0.0
Jun	25	0.0	78.5
Jun	26	0.0	0.0
Jun	27	8.6	0.0
Jun	28	15.0	78.2
Jun	29	0.0	0.0
Jun	30	0.0	0.0
Jul	1	40.8	2.6
Jul	2	0.0	30.1
Jul	3	0.0	31.0
Jul	4	2.5	0.0
Jul	5	0.0	0.0
Jul	6	0.0	0.0
Jul	7	0.0	44.3
Jul	8	8.0	6.0
Jul	9	0.4	0.5
Jul	10	5.2	3.7
Jul	11	0.0	0.0

Jul	12	0.0	0.0
Jul	13	0.0	0.0
Jul	14	0.0	55.2
Jul	15	52.5	34.1
Jul	16	0.0	0.0
Jul	17	0.0	0.0
Jul	18	5.3	0.0
Jul	19	42.4	0.0
Jul	20	50.5	36.8
Jul	21	31.5	0.0
Jul	22	0.0	4.1
Jul	23	74.0	0.0
Jul	24	1.0	0.0
Jul	25	163.8	16.2
Jul	26	0.0	0.0
Jul	27	17.6	74.5
Jul	28	57.1	0.0
Jul	29	0.0	0.0
Jul	30	0.0	77.5
Jul	31	52.1	0.0
Aug	1	2.1	0.0
Aug	2	0.0	5.8
Aug	3	0.0	13.6
Aug	4	0.0	0.0
Aug	5	0.0	47.2
Aug	6	72.8	28.1
Aug	7	0.0	143.0
Aug	8	50.7	0.0
Aug	9	9.5	0.0
Aug	10	0.0	55.3
Aug	11	84.2	0.0
Aug	12	22.5	0.0
Aug	13	0.0	61.7
Aug	14	34.8	4.6
Aug	15	0.0	0.0
Aug	16	0.0	49.3
Aug	17	6.3	7.7
Aug	18	6.4	37.0
Aug	19	51.6	28.5
Aug	20	0.8	0.0
Aug	21	0.0	0.0
Aug	22	26.2	0.0
Aug	23	0.0	0.0
Aug	24	11.1	27.7

Aug	25	115.4	0.0
Aug	26	1.2	1.7
Aug	27	0.0	51.3
Aug	28	24.8	39.2
Aug	29	0.0	15.3
Aug	30	0.0	9.3
Aug	31	0.7	0.0
Sep	1	0.0	50.4
Sep	2	40.8	0.0
Sep	3	4.2	4.2
Sep	4	12.8	0.0
Sep	5	45.0	0.0
Sep	6	0.0	33.9
Sep	7	0.0	0.0
Sep	8	49.2	3.8
Sep	9	0.0	25.0
Sep	10	0.0	6.2
Sep	11	0.0	0.0
Sep	12	0.0	0.0
Sep	13	3.8	0.0
Sep	14	0.0	0.0
Sep	15	0.0	0.0
Sep	16	2.5	0.0
Sep	17	0.0	0.0
Sep	18	33.9	0.0
Sep	19	0.0	0.0
Sep	20	0.0	0.0
Sep	21	0.0	0.0
Sep	22	0.0	0.0
Sep	23	7.8	0.0
Sep	24	0.0	0.0
Sep	25	5.6	0.0
Sep	26	0.0	0.0
Sep	27	0.0	0.0
Sep	28	0.0	0.0
Sep	29	0.0	0.0
Sep	30	0.0	0.0
Oct	1	0.0	0.0
Oct	2	0.0	0.0
Oct	3	0.0	0.0
Oct	4	0.0	0.0
Oct	5	0.0	0.0
Oct	6	0.0	0.0
Oct	7	0.0	0.0

Oct	8	0.0	0.0
Oct	9	0.0	0.0
Oct	10	0.0	0.0
Oct	11	0.0	0.0
Oct	12	0.0	0.0
Oct	13	0.0	0.0
Oct	14	0.0	0.0
Oct	15	0.0	0.0
Oct	16	0.0	0.0
Oct	17	0.0	0.0
Oct	18	0.0	0.0
Oct	19	0.0	0.0
Oct	20	0.0	0.0
Oct	21	0.0	0.0
Oct	22	0.0	0.0
Oct	23	0.0	0.0
Oct	24	0.0	18.6
Oct	25	0.0	0.0
Oct	26	0.0	0.0
Oct	27	0.0	0.0
Oct	28	0.0	0.0
Oct	29	0.0	0.0
Oct	30	0.0	0.0
Oct	31	0.0	0.0
Nov	1	0.0	0.0
Nov	2	0.0	0.0
Nov	3	0.0	0.0
Nov	4	0.0	0.0
Nov	5	0.0	0.0
Nov	6	0.0	0.0
Nov	7	0.0	0.0
Nov	8	0.0	0.0
Nov	9	0.0	0.0
Nov	10	0.0	0.0
Nov	11	0.0	0.0
Nov	12	0.0	0.0
Nov	13	0.0	0.0
Nov	14	0.0	0.0
Nov	15	0.0	0.0
Nov	16	0.0	0.0
Nov	17	0.0	0.0
Nov	18	0.0	0.0
Nov	19	0.0	0.0
Nov	20	0.0	0.0

Nov	21	0.0	0.0
Nov	22	0.0	0.0
Nov	23	0.0	0.0
Nov	24	0.0	0.0
Nov	25	0.0	0.0
Nov	26	0.0	0.0
Nov	27	0.0	0.0
Nov	28	0.0	0.0
Nov	29	0.0	0.0
Nov	30	0.0	0.0
Dec	1	0.0	0.0
Dec	2	0.0	0.0
Dec	3	0.0	0.0
Dec	4	0.0	0.0
Dec	5	0.0	0.0
Dec	6	0.0	0.0
Dec	7	0.0	0.0
Dec	8	0.0	0.0
Dec	9	0.0	0.0
Dec	10	0.0	0.0
Dec	11	0.0	0.0
Dec	12	0.0	0.0
Dec	13	0.0	0.0
Dec	14	0.0	0.0
Dec	15	0.0	0.0
Dec	16	0.0	0.0
Dec	17	0.0	0.0
Dec	18	0.0	0.0
Dec	19	0.0	0.0
Dec	20	0.0	0.0
Dec	21	0.0	0.0
Dec	22	0.0	0.0
Dec	23	0.0	0.0
Dec	24	0.0	0.0
Dec	25	0.0	0.0
Dec	26	0.0	0.0
Dec	27	0.0	0.0
Dec	28	0.0	0.0
Dec	29	0.0	0.0
Dec	30	0.0	0.0
Dec	31	0.0	0.0

APPENDIXVII

Flood Vulnerability Designations

Designation	Index value
Very small vulnerability to floods	< 0.2
Small vulnerability to flood	0.2 to 0.25
Vulnerability to floods	0.25 to 0.50
High vulnerability to floods	0.50 to 0.75
Very high vulnerability to floods	0.75 to 1

APPENDIX VIII

Flood Risk Designations

Designation	Index value
Very small Risk to floods	< 20
Small Risk to flood	20 to 25
Risk to floods	25 to 50
High Risk to floods	50 to 75
Very high Risk to floods	75 to 100